CHAPTER 5

SUBPART E
GROUND-WATER MONITORING AND CORRECTIVE ACTION

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5.1 INTRODUCTION

The Criteria establish ground-water monitoring and corrective action requirements for all existing and new MSWLF units and lateral expansions of existing units except where the Director of an approved State suspends the requirements because there is no potential for migration of leachate constituents from the unit to the uppermost aquifer. The Criteria include requirements for the location, design, and installation of ground-water monitoring systems and set standards for ground-water sampling and analysis. They also provide specific statistical methods and decision criteria for identifying a significant change in ground-water quality. If a significant change in ground-water quality occurs, the Criteria require an assessment of the nature and extent of contamination followed by an evaluation and implementation of remedial measures.

Portions of this chapter are based on a draft technical document developed for EPA's hazardous waste program. This document, "RCRA Ground-Water Monitoring: Draft Technical Guidance" (EPA/530-R-93-001), is undergoing internal review, and may change. EPA chose to incorporate the information from the draft document into this chapter because the draft contained the most recent information available.

5.2 APPLICABILITY
40 CFR §258.50 (a) & (b)

5.2.1 Statement of Regulation

(a) The requirements in this Part apply to MSWLF units, except as provided in paragraph (b) of this section.

(b) Ground-water monitoring requirements under §258.51 through §258.55 of this Part may be suspended by the Director of an approved State for a MSWLF unit if the owner or operator can demonstrate that there is no potential for migration of hazardous constituents from that MSWLF unit to the uppermost aquifer (as defined in §258.2) during the active life of the unit and the post-closure care period. This demonstration must be certified by a qualified ground-water scientist and approved by the Director of an approved State, and must be based upon:

(1) Site-specific field collected measurements, sampling, and analysis of physical, chemical, and biological processes affecting contaminant fate and transport, and

(2) Contaminant fate and transport predictions that maximize contaminant migration and consider impacts on human health and environment.

5.2.2 Applicability

The ground-water monitoring requirements apply to all existing MSWLF units, lateral expansions of existing units, and new MSWLF units that receive waste after October 9, 1993. The requirements for ground-water monitoring may be suspended if the Director of an approved State finds that no potential exists for migration of hazardous constituents from the MSWLF unit to the uppermost aquifer during the active life of the unit, including closure or post-closure care periods.

The "no potential for migration" demonstration must be based upon site-specific information relevant to the fate and transport of any hazardous constituents that may be expected to be released from the unit. The predictions of fate and transport must identify the maximum anticipated concentrations of constituents migrating to the uppermost aquifer so that a protective assessment of the potential effects to human health and the environment can be made. A successful demonstration could exempt the MSWLF unit from requirements of §§258.51 through 258.55, which include installation of ground-water monitoring systems, and sampling and analysis for both detection and assessment monitoring constituents. *Preparing No-Migration Demonstrations for Municipal Solid Waste Disposal Facilities-Screening Tool* is a guidance document describing a process owners/ operators can use to prepare a no-migration demonstration (NMD) requesting suspension of the ground-water monitoring requirements.

5.2.3 Technical Considerations

All MSWLF units that receive waste after the effective date of Part 258 must comply with the ground-water monitoring requirements. The Director of an approved State may exempt an owner/operator from the ground-water monitoring requirements at §258.51 through §258.55 if the owner or operator demonstrates that there is no potential for hazardous constituent migration to the uppermost aquifer throughout the operating, closure, and post-closure care periods of the unit. Owners and operators of MSWLFs not located in approved States will not be eligible for this waiver and will be required to comply with all ground-water monitoring requirements. The "no-migration" demonstration must be certified by a qualified ground-water scientist and approved by the Director of an approved State. It must be based on site-specific field measurements and sampling and analyses to determine the physical, chemical, and biological processes affecting the fate and transport of hazardous constituents. The demonstration must be supported by site-specific data and predictions of the maximum contaminant migration. Site-specific information must include, at a minimum, the information necessary to evaluate or interpret the effects of the following properties or processes on contaminant fate and transport:

Physical Properties or Processes:

- Aquifer Characteristics, including hydraulic conductivity, hydraulic gradient, effective porosity, aquifer thickness, degree of saturation, stratigraphy, degree of fracturing and secondary porosity of soils and bedrock, aquifer heterogeneity, ground-water discharge, and ground-water recharge areas;

- Waste Characteristics, including quantity, type, and origin (e.g., commercial, industrial, or small quantity generators of unregulated hazardous wastes);

- Climatic Conditions, including annual precipitation, leachate generation estimates, and effects on leachate quality;

- Leachate Characteristics, including leachate composition, solubility, density, the presence of immiscible constituents, Eh, and pH; and

- Engineered Controls, including liners, cover systems, and aquifer controls (e.g., lowering the water table). These should be evaluated under design and failure conditions to estimate their long-term residual performance.

Chemical Properties or Processes:

- Attenuation of contaminants in the subsurface, including adsorption/ desorption reactions, ion exchange, organic content of soil, soil water pH, and consideration of possible reactions causing chemical transformation or chelation.

Biological Processes:

- Microbiological Degradation, which may attenuate target compounds or cause transformations of compounds, potentially forming more toxic chemical species.

The alternative design section of Chapter 5.0 discusses these and other processes that affect contaminant fate and solute transport.

When owners or operators prepare a no-migration demonstration, they must use predictions that are based on maximum contaminant migration both from the unit and through the subsurface media. Assumptions about variables affecting transport should be biased toward over-estimating transport and the anticipated concentrations. Assumptions and site specific data that are used in the fate and transport predictions should conform with transport principles and processes, including adherence to mass-balance and chemical equilibria limitations. Within these physicochemical limitations, assumptions should be biased toward the objective of assessing the maximum potential impact on human health and the environment. The evaluation of site-specific data and assumptions may include some of the following approaches:

- Use of the upper bound of known aquifer parameters and conditions that will maximize contaminant transport (e.g., hydraulic conductivity, effective porosity, horizontal and vertical gradients), rather than average values

- Use of the lower range of known aquifer conditions and parameters that tend to attenuate or retard contaminant transport (e.g., dispersivities, decay coefficients, cation exchange capacities, organic carbon contents, and recharge conditions), rather than average values

- Consideration of the cumulative impacts on water quality, including both existing water quality data and cumulative health risks posed by hazardous constituents likely to migrate from the MSWLF unit and other potential or known sources.

A discussion of mathematical approaches for evaluating contaminant or solute transport is provided in Chapter 5.

5.3 COMPLIANCE SCHEDULE 40 CFR § 258.50 (c)

5.3.1 Statement of Regulation*

***[NOTE: EPA finalized several revisions to 40 CFR Part 258 on October 1, 1993 (58 FR 51536), and these revisions delay the effective date for some categories of landfills. More detail on the content of the revisions is included in the introduction.]**

(c) Owners and operators of MSWLF units must comply with the ground-water monitoring requirements of this part according to the following schedule unless an alternative schedule is specified under paragraph (d):

(1) Existing MSWLF units and lateral expansions less than one mile from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1994;

(2) Existing MSWLF units and lateral expansions greater than one mile but less than two miles from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1995;

(3) Existing MSWLF units and lateral expansions greater than two miles from a drinking water intake (surface or subsurface) must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 by October 9, 1996;

(4) New MSWLF units must be in compliance with the ground-water monitoring requirements specified in §§258.51 - 258.55 before waste can be placed in the unit.

5.3.2 Applicability

The rule establishes a self-implementing schedule for owners or operators in States with programs that are deemed inadequate or not yet approved. As indicated in the Statement of Regulation, this schedule depends on the distance of the MSWLF unit from drinking water sources. Approved States may specify an alternative schedule under §258.50 (d), which is discussed in Section 5.4.

Existing units and lateral expansions less than one mile from a drinking water intake must be in compliance with the ground-water monitoring requirements by October 9, 1994. If the units are greater than one mile but less than two miles from a drinking water intake, they must be in compliance by October 9, 1995. Those units located more than two miles from a drinking water intake must be in compliance by October 9, 1996 (see Table 5-1).

New MSWLF units, defined as units that have not received waste prior to October 9, 1993, must be in compliance with these requirements before receiving waste regardless of the proximity to a water supply intake.

5.3.3 Technical Considerations

For most facilities, these requirements will become applicable 3 to 5 years after the promulgation date of the rule. This period

Table 5-1. Compliance Schedule for Existing Units and Lateral Expansions in States with Unapproved Programs

Distance From Water Supply Intake	Time to Comply From October 9, 1991
One mile or less	3 Years
More than one mile but less than two miles	4 Years
More than two miles	5 Years

should provide sufficient time for the owner or operator to conduct site investigation and characterization studies to comply with the requirements of 40 CFR §258.51 through §258.55. For those facilities closest to drinking water intakes, the period provides 2 to 3 years to assess seasonal variability in ground-water quality. A drinking water intake includes water supplied to a user from either a surface water or ground-water source.

5.4 ALTERNATIVE COMPLIANCE SCHEDULES 40 CFR 258.50 (d)(e) & (g)

5.4.1 Statement of Regulation

(d) The Director of an approved State may specify an alternative schedule for the owners or operators of existing MSWLF units and lateral expansions to comply with the ground-water monitoring requirements specified in §§258.51 - 258.55. This schedule must ensure that 50 percent of all existing MSWLF units are in compliance by October 9, 1994 and all existing MSWLF units are in compliance by October 9, 1996. In setting the compliance schedule, the Director of an approved State must consider potential risks posed by the unit to human health and the environment. The following factors should be considered in determining potential risk:

(1) Proximity of human and environmental receptors;

(2) Design of the MSWLF unit;

(3) Age of the MSWLF unit;

(4) The size of the MSWLF unit;

(5) Types and quantities of wastes disposed, including sewage sludge; and

(6) Resource value of the underlying aquifer, including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users; and

(iii) Ground-water quality and quantity.

(e) Once established at a MSWLF unit, ground-water monitoring shall be conducted throughout the active life and post-closure care period of that MSWLF unit as specified in §258.61.

(f) ***(See Section 5.5 for technical guidance on qualifications of a ground-water scientist.)***

(g) The Director of an approved State may establish alternative schedules for demonstrating compliance with §258.51(d)(2), pertaining to notification of placement of certification in operating record; § 258.54(c)(1), pertaining to notification that statistically significant increase (SSI) notice is in operating record; § 258.54(c)(2) and (3), pertaining to an assessment monitoring program; § 258.55(b), pertaining to sampling and analyzing Appendix II constituents; §258.55(d)(1), pertaining to placement of notice (Appendix II constituents detected) in record and notification of notice in record; § 258.55(d)(2), pertaining to sampling for Appendix I and II; § 258.55(g), pertaining to notification (and placement of notice in record) of SSI above ground-water protection standard; § 258.55(g)(1)(iv) and § 258.56(a), pertaining to assessment of corrective measures; § 258.57(a), pertaining to selection of remedy and notification of placement in record; § 258.58(c)(4), pertaining to notification of placement in record (alternative corrective action measures); and § 258.58(f), pertaining to notification of placement in record (certification of remedy completed).

5.4.2 Applicability

The Director of an approved State may establish an alternative schedule for requiring owners/operators of existing units and lateral expansions to comply with the ground-water monitoring requirements. The alternative schedule is to ensure that at least fifty percent of all existing MSWLF units within a given State are in compliance by October 9, 1994 and that all units are in compliance by October 9, 1996.

In establishing the alternative schedule, the Director of an approved State may use site-specific information to assess the relative risks posed by different waste management units and will allow priorities to be developed at the State level. This site-specific information (e.g., proximity to receptors, proximity and withdrawal rate of ground-water users, waste quantity, type, containment design and age) should enable the Director to assess potential risk to the uppermost aquifer. The resource value of the aquifer to be monitored (e.g., ground-water quality and quantity, present and future uses, and withdrawal rate of ground-water users) also may be considered.

Once ground-water monitoring has been initiated, it must continue throughout the active life, closure, and post-closure care periods. The post-closure period may last up to 30 years or more after the MSWLF unit has received a final cover.

In addition to establishing alternative schedules for compliance with ground-water monitoring requirements, the Director of an approved State may establish alternative schedules for certain sampling and analysis requirements of §§258.54 and 258.55, as well as corrective action requirements of §§258.56, 258.57, and 258.58. See Table 5-2 for a summary of notification requirements for which approved States may establish alternative schedules.

5.4.3 Technical Considerations

The rule allows approved States flexibility in establishing alternate ground-water monitoring compliance schedules. In setting an alternative schedule, the State will consider potential impacts to human health and the environment. Approved States have the option to address MSWLF units that have environmental problems immediately. In establishing alternative schedules for installing ground-water monitoring systems at existing MSWLF units, the Director of an approved State may consider information including the age and design of existing facilities. Using this type of information, in conjunction with a knowledge of the wastes disposed, the Director should be able to qualitatively assess or rank facilities based on their risk to local ground-water resources.

5.5 QUALIFICATIONS 40 CFR 258.50 (f)

5.5.1 Statement of Regulation

(f) For the purposes of this Subpart, a qualified ground-water scientist is a scientist or engineer who has received a baccalaureate or post-graduate degree in

Table 5-2. Summary of Notification Requirements

Section	Description
§258.51(d)(2)	14 day notification period after well installation certification by a qualified ground-water scientist (GWS)
§258.54(c)(1)	14 day notification period after finding a statistical increase over background for detection parameter(s)
§258.55(d)(1)	14 day notification period after detection of Appendix II constituents
§258.57(a)	14 day notification period after selection of corrective measures
§258.58(c)(4)	14 day notification period prior to implementing alternative measures
§258.58(f)	14 day notification period after remedy has been completed and certified by GWS

the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by State registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

5.5.2 Applicability

The qualifications of a ground-water scientist are defined to ensure that professionals of appropriate capability and judgement are consulted when required by the Criteria. The ground-water scientist must possess the fundamental education and experience necessary to evaluate ground-water flow, ground-water monitoring systems, and ground-water monitoring techniques and methods. A ground-water scientist must understand and be able to apply methods to solve solute transport problems and evaluate ground-water remedial technologies. His or her education may include undergraduate or graduate studies in hydrogeology, ground-water hydrology, engineering hydrology, water resource engineering, geotechnical engineering, geology, ground-water modeling/ground-water computer modeling, and other aspects of the natural sciences. The qualified ground-water scientist must have a college degree but need not have professional certification, unless required at the State or Tribal level. Some States/Tribes may have certification programs for ground-water scientists; however, there are no recognized Federal certification programs.

5.5.3 Technical Considerations

A qualified ground-water scientist must certify work performed pursuant to the following provisions of the ground-water monitoring and corrective action requirements:

- No potential for migration demonstration (§258.50(b))
- Specifications concerning the number, spacing, and depths of monitoring wells (§258.51(d))
- Determination that contamination was caused by another source or that a statistically significant increase resulted from an error in sampling, analysis, or evaluation (§§258.54 (c)(3) and 258.55 (g)(2))
- Determination that compliance with a remedy requirement is not technically practicable (§258.58(c)(1))
- Completion of remedy (§258.58(f)).

The owner or operator must determine that the professional qualifications of the ground-water specialist are in accordance with the regulatory definition. In general, a certification is a signed document that transmits some finding (e.g., that monitoring wells were installed according to acceptable practices and standards at locations and depths appropriate for a given facility). The certification must be placed in the operating record of the facility, and the State Director must be notified that the certification has been made. Specific details of these certifications will be addressed in the order in which they appear in this guidance document.

Many State environmental regulatory agencies have ground-water scientists on staff. The owner or operator of a MSWLF unit or facility is not necessarily required to obtain certification from an independent (e.g., consulting) ground-water scientist and may, if agreed to by the Director in an approved State, obtain approval by the Director in lieu of certification by an outside individual.

5.6 GROUND-WATER MONITORING SYSTEMS 40 CFR §258.51 (a)(b)(d)

5.6.1 Statement of Regulation

(a) A ground-water monitoring system must be installed that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield ground-water samples from the uppermost aquifer (as defined in §258.2) that:

(1) Represent the quality of background ground water that has not been affected by leakage from a unit. A determination of background quality may include sampling of wells that are not hydraulically upgradient of the waste management area where:

(i) Hydrogeologic conditions do not allow the owner or operator to determine what wells are hydraulically upgradient; or

(ii) Sampling at other wells will provide an indication of background ground-water quality that is as representative or more representative than that provided by the upgradient wells; and

(2) Represent the quality of ground water passing the relevant point of compliance specified by the Director of an approved State under §258.40(d) or at the waste management unit boundary in unapproved States. The downgradient monitoring system must be installed at the relevant point of compliance specified by the Director of an approved State under §258.40(d) or at the waste management unit boundary in unapproved States that ensures detection of ground-water contamination in the uppermost aquifer. When physical obstacles preclude installation of ground-water monitoring wells at the relevant point of compliance at existing units, the down-gradient monitoring system may be installed at the closest practicable distance hydraulically down-gradient from the relevant point of compliance or specified by the Director of an approved State under §258.40 that ensures detection of ground-water contamination in the uppermost aquifer.

(b) The Director of an approved State may approve a multi-unit ground-water monitoring system instead of separate ground-water monitoring systems for each MSWLF unit when the facility has several units, provided the multi-unit ground-water monitoring system meets the requirement of §258.51(a) and will be as protective of human health and the environment as individual monitoring systems for each MSWLF unit, based on the following factors:

(1) Number, spacing, and orientation of the MSWLF units;

(2) Hydrogeologic setting;

(3) Site history;

(4) Engineering design of the MSWLF units; and

(5) Type of waste accepted at the MSWLF units.

(c) (See Section 5.7 for technical guidance on monitoring well design and construction.)

(d) The number, spacing, and depths of monitoring systems shall be:

(1) Determined based upon site-specific technical information that must include thorough characterization of:

(i) Aquifer thickness, ground-water flow rate, ground-water flow direction including seasonal and temporal fluctuations in ground-water flow; and

(ii) Saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials comprising the uppermost aquifer, and materials comprising the confining unit defining the lower boundary of the uppermost aquifer; including, but not limited to: thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities and effective porosities.

(2) Certified by a qualified ground-water scientist or approved by the Director of an approved State. Within 14 days of this certification, the owner or operator must notify the State Director that the certification has been placed in the operating record.

5.6.2 Applicability

The requirements for establishing a ground-water monitoring system pursuant to §258.51 apply to all new units, existing units, and lateral expansions of existing units according to the schedules identified in 40 CFR §258.50. A ground-water monitoring system consists of both background wells and wells located at the point of compliance or waste management unit boundary (i.e., downgradient wells). The ground-water monitoring network must be capable of detecting a release from the MSWLF unit. A sufficient number of monitoring wells must be located downgradient of the unit and be screened at intervals in the uppermost aquifer to ensure contaminant detection. Generally, upgradient wells are used to determine background ground-water quality.

The downgradient wells must be located at the relevant point of compliance specified by the Director of an approved State, or at the waste management unit boundary in States that are not in compliance with regulations. If existing physical structures obstruct well placement, the downgradient monitoring system should be placed as close to the relevant point of compliance as possible. Wells located at the relevant point of compliance must be capable of detecting contaminant releases from the MSWLF unit to the uppermost aquifer. As discussed earlier in the section pertaining to the designation of a relevant point of compliance (Section 4.4), the point of compliance must be no greater than 150 meters from the unit boundary.

The Director of an approved State may allow the use of a multi-unit ground-water monitoring system. MSWLF units in

States that are deemed not in compliance with the regulations must have a monitoring system for each unit.

A qualified ground-water scientist must certify that the number, spacing, and depths of the monitoring wells are appropriate for the MSWLF unit. This certification must be placed in the operating records. The State Director must be notified within 14 days that the certification was placed in the operating record.

5.6.3 Technical Considerations

The objective of a ground-water monitoring system is to intercept ground water that has been contaminated by leachate from the MSWLF unit. Early contaminant detection is important to allow sufficient time for corrective measures to be developed and implemented before sensitive receptors are significantly affected. To accomplish this objective, the monitoring wells should be located to sample ground water from the uppermost aquifer at the closest practicable distance from the waste management unit boundary. An alternative distance that is protective of human health and the environment may be granted by the Director of an approved State. Since the monitoring program is intended to operate through the post-closure period, the location, design, and installation of monitoring wells should address both existing conditions and anticipated facility development, as well as expected changes in ground-water flow.

Uppermost Aquifer

Monitoring wells must be placed to provide representative ground-water samples from the uppermost aquifer. The uppermost aquifer is defined in §258.2 as "the geologic formation nearest to the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility property boundary." These lower aquifers may be separated physically from the uppermost aquifer by less permeable strata (having a lower hydraulic conductivity) that are often termed aquitards. An aquitard is a less permeable geologic unit or series of closely layered units (e.g., silt, clay, or shale) that in itself will not yield significant quantities of water but will transmit water through its thickness. Aquitards may include thicker stratigraphic sequences of clays, shales, and dense, unfractured crystalline rocks (Freeze and Cherry, 1979).

To be considered part of the uppermost aquifer, a lower zone of saturation must be hydraulically connected to the uppermost aquifer within the facility property boundary. Generally, the degree of communication between aquifers is evaluated by ground-water pumping tests. Methods have been devised for use in analyzing aquifer test data. A summary is presented in *Handbook: Ground Water*, Vol. II (USEPA, 1991). The following discussions under this section (5.6.3) should assist the owner or operator in characterizing the uppermost aquifer and the hydrogeology of the site.

Determination of Background Ground-Water Quality

The goal of monitoring-well placement is to detect changes in the quality of ground water resulting from a release from the MSWLF unit. The natural chemical composition of ground water is controlled primarily by the mineral composition of the geologic unit comprising the aquifer. As ground water moves from one geologic unit to another, its chemical composition may change. To reduce the probability of detecting naturally occurring differences in ground-water quality between background and downgradient locations, only ground-water samples collected from the same geologic unit should be compared.

Ground-water quality in areas where the geology is complex can be difficult to characterize. As a result, the rule allows the owner or operator flexibility in determining where to locate wells that will be used to establish background water quality.

If the facility is new, ground-water samples collected from both upgradient and downgradient locations prior to waste disposal can be used to establish background water quality. The sampling should be conducted to account for both seasonal and spatial variability in ground-water quality.

Determining background ground-water quality by sampling wells that are not hydraulically upgradient may be necessary where hydrogeologic conditions do not allow the owner or operator to determine which wells are hydraulically upgradient. Additionally, background ground-water quality may be determined by sampling wells that provide ground-water samples as representative or more representative than those provided by upgradient wells. These conditions include the following:

- The facility is located above an aquifer in which ground-water flow directions change seasonally.
- The facility is located near production wells that influence the direction of ground-water flow.
- Upgradient ground-water quality is affected by a source of contamination other than the MSWLF unit.
- The proposed or existing landfill overlies a ground-water divide or local source of recharge.
- Geologic units present at downgradient locations are absent at upgradient locations.
- Karst terrain or fault zones modify flow.
- Nearby surface water influences ground-water flow directions.
- Waste management areas are located close to a property boundary that is upgradient of the facility.

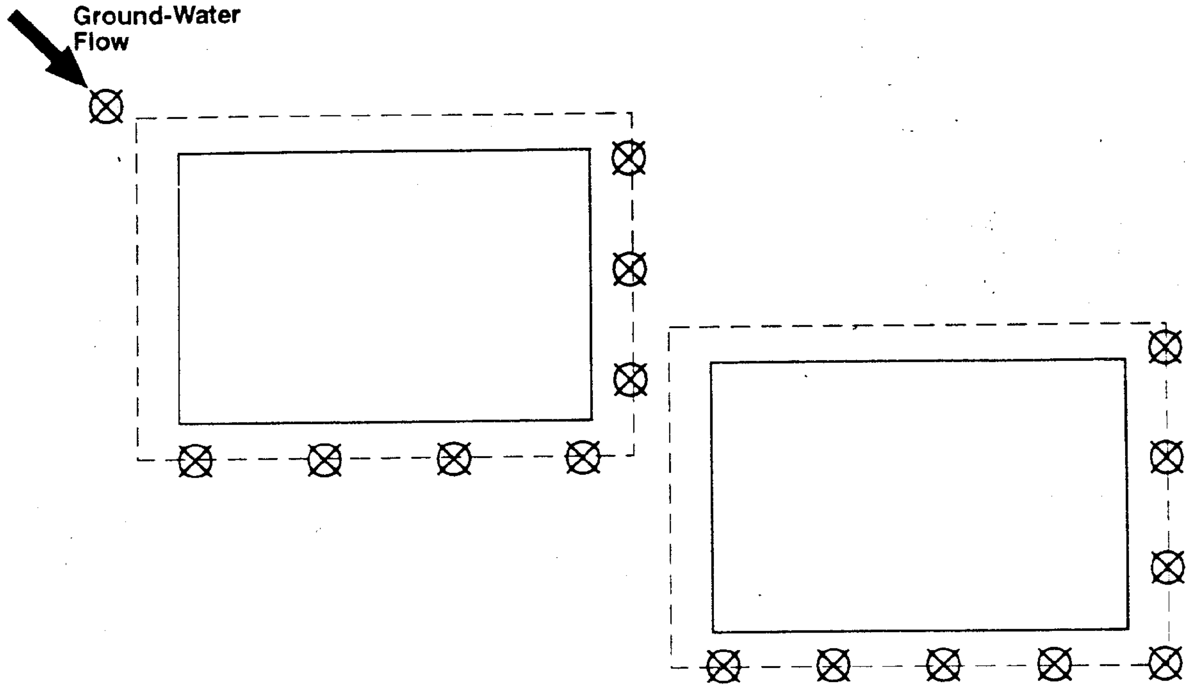
Multi-Unit Monitoring Systems

A multi-unit ground-water monitoring system does not have wells at individual MSWLF unit boundaries. Instead, an imaginary line is drawn around all of the units at the facility. (See Figure 5-1 for a comparison of single unit and multi-unit systems.) This line constitutes the relevant point of compliance. The option to establish a multi-unit monitoring system is restricted to facilities located in approved States. A multi-unit system must be approved by the Director of an approved State after consideration has been given to the:

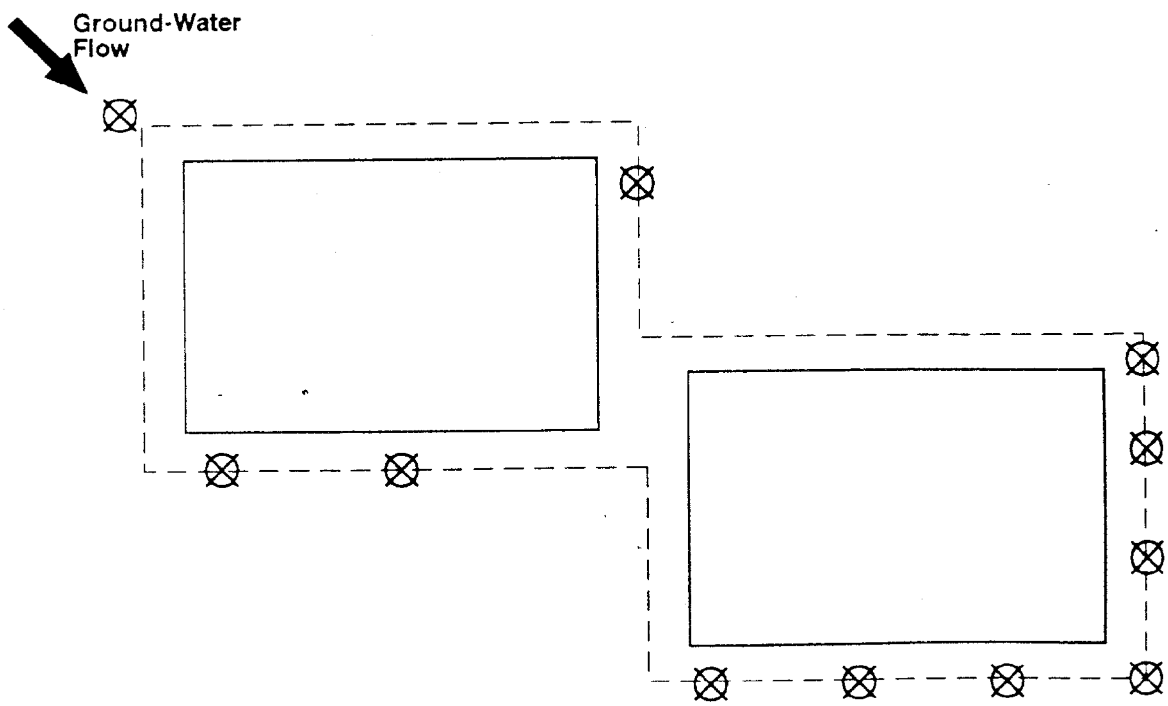
- Number, spacing, and orientation of the MSWLF units

Figure 5-1. Comparison of Single Unit and Multi-Unit Monitoring System

Single-Unit System



Multi-Unit System



- Hydrogeologic setting
- Site history
- Engineering design of the MSWLF units
- Type of wastes accepted at the facility.

The purpose of a multi-unit system is to reduce the number of monitoring wells that can provide the same information. The conceptual design of the multi-unit system should consider the use and management of the facility with respect to anticipated unit locations. In some cases, it may be possible to justify a reduction in the number of wells if the waste management units are aligned along the same flow path in the ground-water system.

The multi-unit monitoring system must provide a level of protection to human health and the environment that is comparable to monitoring individual units. The multi-unit system should allow adequate time after detection of contamination to develop and implement corrective measures before sensitive receptors are adversely affected.

Hydrogeological Characterization

Adequate monitoring-well placement depends on collecting and evaluating hydrogeological information that can be used to form a conceptual model of the site. The goal of a hydrogeological investigation is to acquire site-specific data concerning:

- The lateral and vertical extent of the uppermost aquifer
- The lateral and vertical extent of the upper and lower confining units/layers
- The geology at the owner's/operator's facility (e.g, stratigraphy, lithology, and structural setting)
- The chemical properties of the uppermost aquifer and its confining layers relative to local ground-water chemistry and wastes managed at the facility
- Ground-water flow, including:
  - The vertical and horizontal directions of ground-water flow in the uppermost aquifer
  - The vertical and horizontal components of the hydraulic gradient in the uppermost and any hydraulically connected aquifer
  - The hydraulic conductivities of the materials that comprise the upper-most aquifer and its confining units/layers
  - The average linear horizontal velocity of ground-water flow in the uppermost aquifer.

The elements of a program to characterize the hydrogeology of a site are discussed briefly in the sections that follow and are addressed in more detail in "RCRA Ground-Water Monitoring: Draft Technical Guidance" (USEPA, 1992a).

Prior to initiating a field investigation, the owner or operator should perform a preliminary investigation. The preliminary investigation will involve reviewing all available information about the site, which may consist of:

- Information on the waste management history of the site, including:
  - A chronological history of the site, including descriptions of wastes managed on-site
  - A summary of documented releases
  - Details on the structural integrity of the MSWLF unit and physical controls on waste migration
- A literature review, including:
  - Reports of research performed in the area of the site
  - Journal articles
  - Studies and reports available from local, regional, and State offices (e.g., geologic surveys, water boards, and environmental agencies)
  - Studies available from Federal offices, such as USGS or USEPA
- Information from file searches, including:
  - Reports of previous investigations at the site
  - Geological and environmental assessment data from State and Federal reports.

The documentation itemized above is by no means a complete listing of information available for a preliminary investigation. Many other sources of hydrogeological information may be available for review during the preliminary investigation.

Characterizing Site Geology

After the preliminary investigation is complete, the owner/operator will have information that he/she can use to develop a plan to characterize site hydrogeology further.

Nearly all hydrogeological investigations include a subsurface boring program. A boring program is necessary to define site hydrogeology and the small-scale geology of the area beneath the site. The program usually requires more than one iteration. The objective of the initial boreholes is to refine the conceptual model of the site derived from the preliminary investigation.

The subsurface boring program should be designed as follows:

- The initial number of boreholes and their spacing is based on the information obtained during the preliminary investigation.
- Additional boreholes should be installed as needed to provide more information about the site.
- Samples should be collected from the borings at changes in lithology. For boreholes that will be completed as monitoring wells, at least one sample should be collected from the interval that will be the screened interval. Boreholes that will not be completed as monitoring wells must be properly decommissioned.

Geophysical techniques, cone penetrometer surveys, mapping programs, and laboratory analyses of borehole samples can be used to plan and supplement the subsurface boring program. Downhole geophysical techniques include electric, sonic, and nuclear logging. Surface geophysical techniques include seismic reflection and refraction, as well as electromagnetic induction and resistivity.

The data obtained from the subsurface boring program should enable the owner or operator to identify:

- Lithology, soil types, and stratigraphy
- Zones of potentially high hydraulic conductivity
- The presence of confining formations or layers
- Unpredicted geologic features, such as fault zones, cross-cutting structures, and pinch-out zones
- Continuity of petrographic features, such as sorting, grain size distribution, and cementation
- The potentiometric surface or water table.

Characterizing Ground-Water Flow Beneath the Site

In addition to characterizing site geology, the owner/operator should characterize the hydrology of the uppermost aquifer and its confining layer(s) at the site. The owner or operator should install wells and/or piezometers to assist in characterizing site hydrology. The owner/operator should determine and assess:

- The direction(s) and rate(s) of ground-water flow (including both horizontal and vertical components of flow)
- Seasonal/temporal, natural, and artificially induced (e.g., off-site production well-pumping, agricultural use) short-term and long-term variations in ground-water elevations and flow patterns
- The hydraulic conductivities of the stratigraphic units at the site, including vertical hydraulic conductivity of the confining layer(s).

Determining Ground-Water Flow Direction and Hydraulic Gradient

Installing monitoring wells that will provide representative background and downgradient water samples requires a thorough understanding of how ground water flows beneath a site. Developing such an understanding requires obtaining information regarding both ground-water flow direction(s) and hydraulic gradient. Ground-water flow direction can be thought of as the idealized path that ground-water follows as it passes through the subsurface. Hydraulic gradient (i) is the change in static head per unit of distance in a given direction. The static head is defined as the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point (i.e., the sum of the elevation head and pressure head).

To determine ground-water flow directions and hydraulic gradient, owners and operators should develop and implement a water level-monitoring program. This program should be structured to provide precise water level measurements in a sufficient number of piezometers or wells at a sufficient frequency to gauge both seasonal average flow directions and temporal fluctuations in ground-water flow directions. Ground-water flow direction(s) should be determined from water levels measured in wells screened in the same hydro-stratigraphic position. In heterogeneous geologic settings (i.e., settings in which the hydraulic conductivities of the subsurface materials vary with location in the subsurface), long well screens can intercept stratigraphic horizons with different (e.g., contrasting) ground-water flow directions and different heads. In this situation, the resulting water levels will not provide the depth-discrete head measurements required for accurate determination of the ground-water flow direction.

In addition to evaluating the component of ground-water flow in the horizontal direction, a program should be undertaken to assess the vertical component of ground-water flow. Vertical ground-water flow information should be based, at least in part, on field data from wells and piezometers, such as multi-level wells, piezometer clusters, or multi-level sampling devices, where appropriate. The following sections provide acceptable methods for assessing the vertical and horizontal components of flow at a site.

Ground-Water Level Measurements

To determine ground-water flow directions and ground-water flow rates, accurate water level measurements (measured to the nearest 0.01 foot) should be obtained. Section 5.8 delineates procedures for obtaining water level measurements. At facilities where it is known or plausible that immiscible contaminants (i.e., non-aqueous phase liquids (NAPLs)) occur (or are determined to be potentially present after considering the waste types managed at the facility) in the subsurface at the facility, both the depth(s) to the immiscible layer(s) and the thickness(es) of the immiscible layer(s) in the well should be recorded.

For the purpose of measuring total head, piezometers and wells should have as short a screened interval as possible. Specifically, the screens in piezometers or wells that are used to measure head should generally be less than 10 feet long. In circumstances including the following, well screens longer than 10 feet may be warranted:

- Natural water level fluctuations necessitate a longer screen length.
- The interval monitored is slightly greater than the appropriate screen length (e.g., the interval monitored is 12 feet thick).
- The aquifer monitored is homogeneous and extremely thick (e.g., greater than 300 feet); thus, a longer screen (e.g., a 20-foot screen) represents a fairly discrete interval.

The head measured in a well with a long screened interval is a function of all of the different heads over the entire length of the screened interval. Care should be taken when interpreting water levels collected from wells that have long screened intervals (e.g., greater than 10 feet).

The water-level monitoring program should be structured to provide precise water level measurements in a sufficient number of piezometers or wells at a sufficient frequency to gauge both seasonal average flow directions and temporal fluctuations in ground-water flow directions. The owner/operator should determine and assess seasonal/temporal, natural, and artificially induced (e.g., off-site production well-pumping, agricultural use) short-term and long-term variations in ground-water elevations, ground-water flow patterns, and ground-water quality.

Establishing Horizontal Flow Direction and the Horizontal Component of Hydraulic Gradient

After the water level data and measurement procedures are reviewed to determine that they are accurate, the data should be used to:

- Construct potentiometric surface maps and water table maps based on the distribution of total head. The data used to develop water table maps should be from piezometers or wells screened across the water table. The data used to develop potentiometric surface maps should be from piezometers or wells screened at approximately the same elevation in the same hydrostratigraphic unit;

- Determine the horizontal direction(s) of ground-water flow by drawing flow lines on the potentiometric surface map or water table map (i.e., construct a flow net);

- Calculate value(s) for the horizontal and vertical components of hydraulic gradient.

Methods for constructing potentiometric surface and water table maps, constructing flow nets, and determining the direction(s) of ground-water flow are provided by USEPA (1989c) and Freeze and Cherry (1979). Methods for calculating hydraulic gradient are provided by Heath (1982) and USEPA (1989c).

A potentiometric surface or water table map will give an approximate idea of general ground-water flow directions. However, to locate monitoring wells properly, ground-water flow direction(s) and hydraulic gradient(s) should be established in both the horizontal and vertical directions and over time at regular intervals (e.g., over a 1-year period at 3-month intervals).

Establishing Vertical Flow Direction and the Vertical Component of Hydraulic Gradient

To make an adequate determination of the ground-water flow directions, the vertical component of ground-water flow should be evaluated directly. This generally requires the installation of multiple piezometers or wells in clusters or nests, or the installation of multi-level wells or sampling devices. A piezometer or well nest is a closely spaced group of piezometers or wells screened at different depths, whereas a multi-level well is a single device. Both piezometer/well nests and multi-level wells allow for the measurement of vertical variations in hydraulic head.

When reviewing data obtained from multiple placement of piezometers or wells in single boreholes, the construction details of the well should be carefully evaluated. Not only is it extremely difficult to seal several piezometers/wells at discrete depths within a single borehole, but sealant materials may migrate from the seal of one piezometer/well to the screened interval of another piezometer/well. Therefore, the design of a piezometer/well nest should be considered carefully. Placement of piezometers/wells in closely spaced boreholes, where piezometers/wells have been screened at different, discrete depth intervals, is likely to produce more accurate information. The primary concerns with the installation of piezometers/wells in closely spaced, separate boreholes are: 1) the disturbance of geologic and soil materials that occurs when one piezometer is installed may be reflected in the data obtained from another piezometer located nearby, and 2) the analysis of water levels measured in piezometers that are closely spaced, but separated horizontally, may produce imprecise information regarding the vertical component of ground-water flow. The limitations of installing multiple piezometers either in single or separate boreholes may be overcome by the installation of single multi-level monitoring wells or sampling devices in single boreholes. The advantages and disadvantages of these types of devices are discussed by USEPA (1989f).

The owner or operator should determine the vertical direction(s) of ground-water flow using the water levels measured in multi-level wells or piezometer/well nests to construct flow nets. Flow nets should depict the piezometer/well depth and length of the screened interval. It is important to portray the screened interval accurately on the flow net to ensure that the piezometer/well is actually monitoring the desired water-bearing unit. A flow net should be developed from information obtained from piezometer/ well clusters or nests screened at different, discrete depths. Detailed guidance for the construction and evaluation of flow nets in cross section (vertical flow nets) is provided by USEPA (1989c). Further information can be obtained from Freeze and Cherry (1979).

Determining Hydraulic Conductivity

Hydraulic conductivity is a measure of a material's ability to transmit water. Generally, poorly sorted silty or clayey materials have low hydraulic conductivities, whereas well-sorted sands and gravels have high hydraulic conductivities. An aquifer may be classified as either homogeneous or heterogeneous and either isotropic or anisotropic according to the way its hydraulic conductivity varies in space. An aquifer is <u>homogeneous</u> if the hydraulic conductivity is independent of location within the aquifer; it is <u>heterogeneous</u> if hydraulic conductivities are dependent on location within the aquifer. If the hydraulic conductivity is independent of the direction of measurement at a point in a geologic formation, the formation is <u>isotropic</u> at that point. If the hydraulic conductivity varies with the direction of measurement at a point, the formation is <u>anisotropic</u> at that point.

Determining Hydraulic Conductivity Using Field Methods

Sufficient aquifer testing (i.e., field methods) should be performed to provide representative estimates of hydraulic conductivity. Acceptable field methods include conducting aquifer tests with single wells, conducting aquifer tests with multiple wells, and using flowmeters. This section provides brief overviews of these methods, including two methods for obtaining vertically discrete measurements of hydraulic conductivity. The identified references provide detailed descriptions of the methods summarized in this section.

A commonly used test for determining horizontal hydraulic conductivity with a single well is the slug test. A slug test is performed by suddenly adding, removing, or displacing a known volume of water from a well and observing the time that it takes for the water level to recover to its original level (Freeze and Cherry, 1979). Similar results can be achieved by pressurizing the well casing, depressing the water level, and suddenly releasing the pressure to simulate the removal of water from the well. In most cases, EPA recommends that water not be introduced into wells during aquifer tests to avoid altering ground-water chemistry. Single-well tests are limited in scope to the area directly adjacent to the well screen. The vertical extent of the well screen generally defines the part of the geologic formation that is being tested.

A modified version of the slug test, known as the multilevel slug test, is capable of providing depth-discrete measurements of hydraulic conductivity. The drawback of the multilevel slug test is that the test relies on the ability of the investigator to isolate a portion of the aquifer using a packer. Nevertheless, multilevel slug tests, when performed properly, can produce reliable measurements of hydraulic conductivity.

Multiple-well tests involve withdrawing water from, or injecting water into, one well, and obtaining water level measurements over time in observation wells. Multiple-well tests are often performed as pumping tests in which water is pumped from one well and drawdown is observed in nearby wells. A step-drawdown test should precede most pumping tests to determine an appropriate discharge rate. Aquifer tests conducted with wells screened in the same water-bearing zone can be used to provide hydraulic conductivity data for that zone. Multiple-well tests for hydraulic conductivity characterize a greater proportion of the subsurface than single-well tests and, thus, provide average values of hydraulic conductivity. Multiple-well tests require measurement of parameters similar to those required for single-well tests (e.g., time, drawdown). When using aquifer test data to determine aquifer parameters, it is important that the solution assumptions can be applied to site conditions. Aquifer test solutions are available for a wide variety of hydrogeologic settings, but are often applied incorrectly by inexperienced persons. Incorrect assumptions regarding hydrogeology (e.g., aquifer boundaries, aquifer lithology, and aquifer thickness) may translate into incorrect estimations of hydraulic conductivity. A qualified ground-water scientist with experience in designing and interpreting aquifer tests should be consulted to ensure that aquifer test solution methods fit the hydrogeologic setting. Kruseman and deRidder (1989) provide a comprehensive discussion of aquifer tests.

Multiple-well tests conducted with wells screened in different water-bearing zones furnish information concerning hydraulic communication among the zones. Water levels in these zones should be monitored during the aquifer test to determine the type of aquifer system (e.g., confined, unconfined, semi-confined, or semi-unconfined) beneath the site, and their leakance (coefficient of leakage) and drainage factors (Kruseman and deRidder, 1989). A multiple-well aquifer test should be considered at every site as a method to establish the vertical extent of the uppermost aquifer and to evaluate hydraulic connection between aquifers.

Certain aquifer tests are inappropriate for use in karst terrains characterized by a well-developed conduit flow system, and they also may be inappropriate in fractured bedrock. When a well located in a karst conduit or a large fracture is pumped, the water level in the conduit is lowered. This lowering produces a drawdown that is not radial (as in a granular aquifer) but is instead a trough-like depression parallel to the pumped conduit or fracture. Radial flow equations do not apply to drawdown data collected during such a pump test. This means that a conventional semi-log plot of drawdown versus time is inappropriate for the purpose of determining the aquifer's transmissivity and storativity. Aquifer tests in karst aquifers can be useful, but valid determinations of hydraulic conductivity, storativity, and transmissivity may be impossible. However, an aquifer test can provide information on the presence of conduits, on storage characteristics, and on the percentage of Darcian flow. McGlew and Thomas (1984) provide a more detailed discussion of the appropriate use of aquifer tests in fractured bedrock and on the suitable interpretation of test data. Dye tracing also is used to determine the rate and direction of ground-water flow in karst settings (Section 5.2.4).

Several additional factors should be considered when planning an aquifer test:

- Owners and operators should provide for the proper storage and disposal of potentially contaminated ground water pumped from the well system.

- Owners and operators should consider the potential effects of pumping on existing plumes of contaminated ground water.

- In designing aquifer tests and interpreting aquifer test data, owners/operators should account and correct for seasonal, temporal, and anthropogenic effects on the potentiometric surface or water table. This is usually done by installing piezometers outside the influence of the stressed aquifer. These piezometers should be continuously monitored during the aquifer test.

- Owners and operators should be aware that, in a very high hydraulic conductivity aquifer, the screen size and/or filter pack used in the test well can affect an aquifer test. If a very small screen size is used, and the pack is improperly graded, the test may reflect the characteristics of the filter pack, rather than the aquifer.

- EPA recommends the use of a step-drawdown test to provide a basis for selecting discharge rates prior to conducting a full-scale pumping test. This will ensure that the pumping rate chosen for the subsequent pumping test(s) can be sustained without exceeding the available drawdown of the pumped wells. In addition, this test will produce a measurable drawdown in the observation wells.

Certain flowmeters recently have been recognized for their ability to provide accurate and vertically discrete measurements of hydraulic conductivity. One of these, the impeller flowmeter, is available commercially. More sensitive types of flowmeters (i.e., the heat-pulse flowmeter and electromagnetic flowmeter) should be available in the near future. Use of the impeller flowmeter requires running a caliper log to measure the uniformity of the diameter of the well screen. The well is then pumped with a small pump operated at a constant flow rate. The flowmeter is lowered into the well, and the discharge rate is measured every few feet by raising the flowmeter in the well. Hydraulic conductivity values can be calculated from the recorded data using the Cooper-Jacob (1946) formula for horizontal flow to a well. Use of the impeller flowmeter is limited at sites where the presence of low permeability materials does not allow pumping of the wells at rates sufficient to operate the flowmeter. The application of flowmeters in the measure of hydraulic conductivity is described by Molz et al. (1990) and Molz et al. (1989).

Determining Hydraulic Conductivity Using Laboratory Methods

It may be beneficial to use laboratory measurements of hydraulic conductivity to augment the results of field tests. However, field methods provide the best estimates of hydraulic conductivity in most cases. Because of the limited sample size, laboratory tests can fail to account for secondary porosity features, such as fractures and joints, and hence, can greatly underestimate overall aquifer hydraulic conductivities. Laboratory tests may provide valuable information about the vertical component of hydraulic conductivity of aquifer materials. However, laboratory test results always should be confirmed by field measurements, which sample a much larger portion of the aquifer. In addition, laboratory test results can be profoundly affected by the test method selected and by the manner in which the tests are carried out (e.g., the extent to which sample collection and preparation have changed the in situ hydraulic properties of the tested material). Special attention should be given to the selection of the appropriate test method and test conditions and to quality control of laboratory results. McWhorter and Sunada (1977), Freeze and Cherry (1979), and Sevee (1991) discuss determining hydraulic conductivity in the laboratory. Laboratory tests may provide the best estimates of hydraulic conductivity for materials in the unsaturated zone, but they are likely to be less accurate than field methods for materials in the saturated zone (Cantor et al., 1987).

Determining Ground-Water Flow Rate

The calculation of the average ground-water flow rate (average linear velocity of ground-water flow), or seepage velocity, is discussed in detail in USEPA (1989c), in Freeze and Cherry (1979), and in Kruseman and deRidder (1989). The average linear velocity of ground-water flow ($\bar{v}$) is a function of hydraulic conductivity (K), hydraulic gradient (i), and effective porosity (n_e):

$$\bar{v} = -\frac{Ki}{n_e}$$

Methods for determining hydraulic gradient and hydraulic conductivity have been presented previously. Effective porosity, the percentage of the total volume of a given mass of soil, unconsolidated material, or rock that consists of interconnected pores through which water can flow, should be estimated from laboratory tests or from values cited in the literature. (Fetter (1980) provides a good discussion of effective porosity. Barari and Hedges (1985) provide default values for effective porosity.) USEPA (1989c) provides methods for determining flow rates in heterogeneous and/or anisotropic systems and should be consulted prior to calculating flow rates.

Interpreting and Presenting Data

The following sections offer guidance on interpreting and presenting hydrogeologic data collected during the site characterization process. Graphical representations of data, such as cross sections and maps, are typically extremely helpful both when evaluating data and when presenting data to interested individuals.

Interpreting Hydrogeologic Data

Once the site characterization data have been collected, the following tasks should be undertaken to support and develop the interpretation of these data:

- Review borehole and well logs to identify major rock, unconsolidated material, and soil types and establish their horizontal and vertical extent and distribution.

- From borehole and well log (and outcrop, where available) data, construct representative cross-sections for each MSWLF unit, one in the direction of ground-water flow and one orthogonal to ground-water flow.

- Identify zones of suspected high hydraulic conductivity, or structures likely to influence contaminant migration through the unsaturated and saturated zones.

- Compare findings with other studies and information collected during the preliminary investigation to verify the collected information.

- Determine whether laboratory and field data corroborate and are sufficient to define petrology, effective porosity, hydraulic conductivity, lateral and vertical stratigraphic relationships, and ground-water flow directions and rates.

After the hydrogeologic data are interpreted, the findings should be reviewed to:

- Identify information gaps

- Determine whether the collection of additional data or reassessment of existing data is required to fill in the gaps

- Identify how information gaps are likely to affect the ability to design a RCRA monitoring system.

Generally, lithologic data should correlate with hydraulic properties (e.g., clean, well-sorted, unconsolidated sands should exhibit high hydraulic conductivity). Additional boreholes should be drilled and additional samples should be collected to describe the hydrogeology of the site if the investigator is unable to 1) correlate stratigraphic units between borings, 2) identify zones of potentially high hydraulic conductivity and the thickness and lateral extent of these zones, or 3) identify confining formations/layers and the thickness and lateral extent of these formation layers.

When establishing the locations of wells that will be used to monitor ground water in hydrogeologic settings characterized by ground-water flow in porous media, the following should be documented:

- The ground-water flow rate should be based on accurate measurements of hydraulic conductivity and hydraulic gradient and accurate measurements or estimates of effective porosity

- The horizontal and vertical components of flow should be accurately depicted in flow nets and based on valid data

- Any seasonal or temporal variations in the water table or potentiometric surface, and in vertical flow components, should be determined.

Once an understanding of horizontal and vertical ground-water flow has been established, it is possible to estimate where monitoring wells will most likely intercept contaminant flow.

Presenting Hydrogeologic Data

Subsequent to the generation and interpretation of site-specific geologic data, the data should be presented in geologic cross-sections, topographic maps, geologic maps, and soil maps. The Agency suggests that owners/operators obtain or prepare and review topographic, geologic, and soil maps of the facility, in addition to site maps of the facility and MSWLF units. In cases where suitable maps are not available, or where the information contained on available maps is not complete or accurate, detailed mapping of the site should be performed by qualified and experienced individuals. An aerial photograph and a topographic map of the site should be included as part of the presentation of hydrogeologic data. The topographic map should be constructed under the supervision of a qualified surveyor and should provide contours at a maximum of 2-foot intervals.

Geologic and soil maps should be based on rock, unconsolidated material, and soil identifications gathered from borings and outcrops. The maps should use colors or symbols to represent each soil, unconsolidated material, and rock type that outcrops on the surface. The maps also should show the locations of outcrops and all borings placed during the site characterization. Geologic and soil maps are important because they can provide information describing how site geology fits into the local and regional geologic setting.

Structure contour maps and isopach maps should be prepared for each water-bearing zone that comprises the uppermost aquifer and for each significant confining layer, especially the one underlying the uppermost aquifer. A structure contour map depicts the configuration (i.e., elevations) of the upper or lower surface or boundary of a particular geologic or soil formation, unit, or zone. Structure contour maps are especially important in understanding dense non-aqueous phase liquid (DNAPL) movement because DNAPLs (e.g., tetrachloroethylene) may migrate in the direction of the dip of lower permeability units. Separate structure contour maps should be constructed for the upper and lower surfaces (or contacts) of each zone of interest. Isopach maps should depict contours that indicate the thickness of each zone. These maps are generated from borings and geologic logs and from geophysical measurements. In conjunction with cross-sections, isopach maps may be used to help determine monitoring well locations, depths, and screen lengths during the design of the detection monitoring system.

A potentiometric surface map or water table map should be prepared for each water-bearing zone that comprises the uppermost aquifer. Potentiometric surface and water table maps should show both the direction and rate of ground-water flow and the locations of all piezometers and wells on which they are based. The water level measurements for all piezometers and wells on which the potentiometric surface map or water table map is based should be shown on the potentiometric surface or water table map. If seasonal or temporal variations in ground-water flow occur at the site, a sufficient number of potentiometric surface or water table maps should be prepared to show these variations. Potentiometric surface and water table maps can be combined with structure contour maps for a particular formation or unit. An adequate number of cross sections should be prepared to depict significant stratigraphic and structural trends and to reflect stratigraphic and structural features in relation to local and regional ground-water flow.

Hydrogeological Report

The hydrogeological report should contain, at a minimum:

- A description of field activities
- Drilling and/or well construction logs
- Analytical data
- A discussion and interpretation of the data
- Recommendations to address data gaps.

The final output of the site characterization phase of the hydrogeological investigation is a conceptual model. This model is the integrated picture of the hydrogeologic system and the waste management setting. The final conceptual model must be a site-specific description of the unsaturated zone, the uppermost aquifer, and its confining units. The model should contain all of the information necessary to design a ground-water monitoring system.

Monitoring Well Placement

This section separately addresses the lateral placement and the vertical sampling intervals of point of compliance wells. However, these two aspects of well placement should be evaluated together in the design of the monitoring system. Site-specific hydrogeologic data obtained during the site characterization should be used to determine the lateral placement of detection monitoring wells and to select the length and vertical position of monitoring well intakes. Potential pathways for contaminant migration are three-dimensional. Consequently, the design of a detection monitoring network that intercepts these potential pathways requires a three-dimensional approach.

Lateral Placement of Point of Compliance Monitoring Wells

Point of compliance monitoring wells should be as close as physically possible to the edge of the MSWLF unit(s) and should be screened in all transmissive zones that may act as contaminant transport pathways. The lateral placement of monitoring wells should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways.

Point of compliance monitoring wells should be placed laterally along the downgradient edge of the MSWLF unit to intercept potential pathways for contaminant migration. The local ground-water flow direction and gradient are the major factors in determining the lateral placement of point of compliance wells. In a homogeneous, isotropic hydrogeologic setting, well placement can be based on general aquifer characteristics (e.g., direction and rate of ground-water flow), and potential contaminant fate and transport characteristics (e.g., advection, dispersion). More commonly, however, geology is variable and preferential pathways exist that control the migration of contaminants. These types of heterogeneous, anisotropic geologic settings can have numerous, discrete zones within which contaminants may migrate.

Potential migration pathways include zones of relatively high intrinsic (matrix) hydraulic conductivities, fractured/faulted zones, and subsurface material that may increase in hydraulic conductivity if the material is exposed to waste(s) managed at the site (e.g., a limestone layer that underlies an acidic waste). In addition to natural hydrogeologic features, human-made features may influence the ground-water flow direction and, thus, the lateral placement of point of compliance wells. Such human-made features include ditches, areas where fill material has been placed, buried piping, buildings, leachate collection systems, and adjacent disposal units. The lateral placement of monitoring wells should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways.

In some settings, the ground-water flow direction may reverse seasonally (depending on precipitation), change as a result of tidal influences or river and lake stage fluctuations, or change temporally as a result of well-pumping or changing land use patterns. In other settings, ground water may flow away from the waste management area in all directions. In such cases, EPA recommends that monitoring wells be installed on all sides (or in a circular pattern) around the waste management area to allow for the detection of contamination. In these cases, certain wells may be downgradient only part of the time, but such a configuration should ensure that releases from the unit will be detected.

The lateral placement of monitoring wells also should be based on the physical/chemical characteristics of the contaminants of concern. While the restriction of liquids in MSWLFs may limit the introduction of hazardous constituents into landfills, it is important to consider the physical/chemical characteristics of contaminants when designing the well system. These characteristics include solubility, Henry's Law constant, partition coefficients, specific gravity, contaminant reaction or degradation products, and the potential for contaminants to degrade confining layers. For example, contaminants with low solubilities and high specific gravities that occur as DNAPLs may migrate in the subsurface in directions different from the direction of ground-water flow. Therefore, in situations where the release of DNAPLs is a concern, the lateral placement of compliance point ground-water monitoring wells should not necessarily only be along the downgradient edge of the MSWLF unit. Considering both contaminant characteristics and hydrogeologic properties is important when determining the lateral placement of monitoring wells.

Vertical Placement and Screen Lengths

Proper selection of the vertical sampling interval is necessary to ensure that the monitoring system is capable of detecting a release from the MSWLF unit. The vertical position and lengths of well intakes are functions of (1) hydro-geologic factors that determine the distribution of, and fluid/vapor phase transport within, potential pathways of contaminant migration to and within the uppermost aquifer, and (2) the chemical and physical characteristics of contaminants that control their transport and distribution in the subsurface. Well intake length also is determined by the need to obtain vertically discrete ground-water samples. Owners and operators should determine the probable location, size, and geometry of potential contaminant plumes when selecting well intake positions and lengths.

Site-specific hydrogeologic data obtained during the site characterization should be used to select the length and vertical position of monitoring well intakes. The vertical positions and lengths of monitoring well intakes should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thicknesses of stratigraphic horizons that can serve as contaminant migration pathways. Figure 5-2 illustrates examples of complex stratigraphy that would require multiple vertical monitoring intervals.

The depth and thickness of a potential contaminant migration pathway can be determined from soil, unconsolidated material, and rock samples collected during the boring program, and from samples collected while drilling the monitoring well. Direct physical data can be supplemented by geophysical data, available regional/local hydrogeological data, and other data that provide the vertical distribution of hydraulic conductivity. The vertical sampling interval is not necessarily synonymous with aquifer thickness. Monitoring wells are often screened at intervals that represent a portion of the thickness of the aquifer. When monitoring an unconfined aquifer, the well screen typically should be positioned so that a portion of the well screen is in the saturated zone and a portion of the well screen is in the unsaturated zone (i.e., the well screen straddles the water table). While the restriction of liquids in MSWLFs may limit the introduction of hazardous constituents into landfills, it is important to consider the physical/chemical characteristics of contaminants when designing the well system.

The vertical positions and lengths of monitoring well intakes should be based on the same physical/chemical characteristics of the contaminants of concern that influence the lateral placement of monitoring wells. Considering both contaminant characteristics and hydrogeologic properties is important when choosing the vertical position and length of the well intake. Some contaminants may migrate within very narrow zones. Of course, for well placement at a new site, it is unlikely that the owner or operator will be able to assess contaminant characteristics.

Different transport processes control contaminant migration depending on whether the contaminant dissolves or is immiscible in water. Immiscible

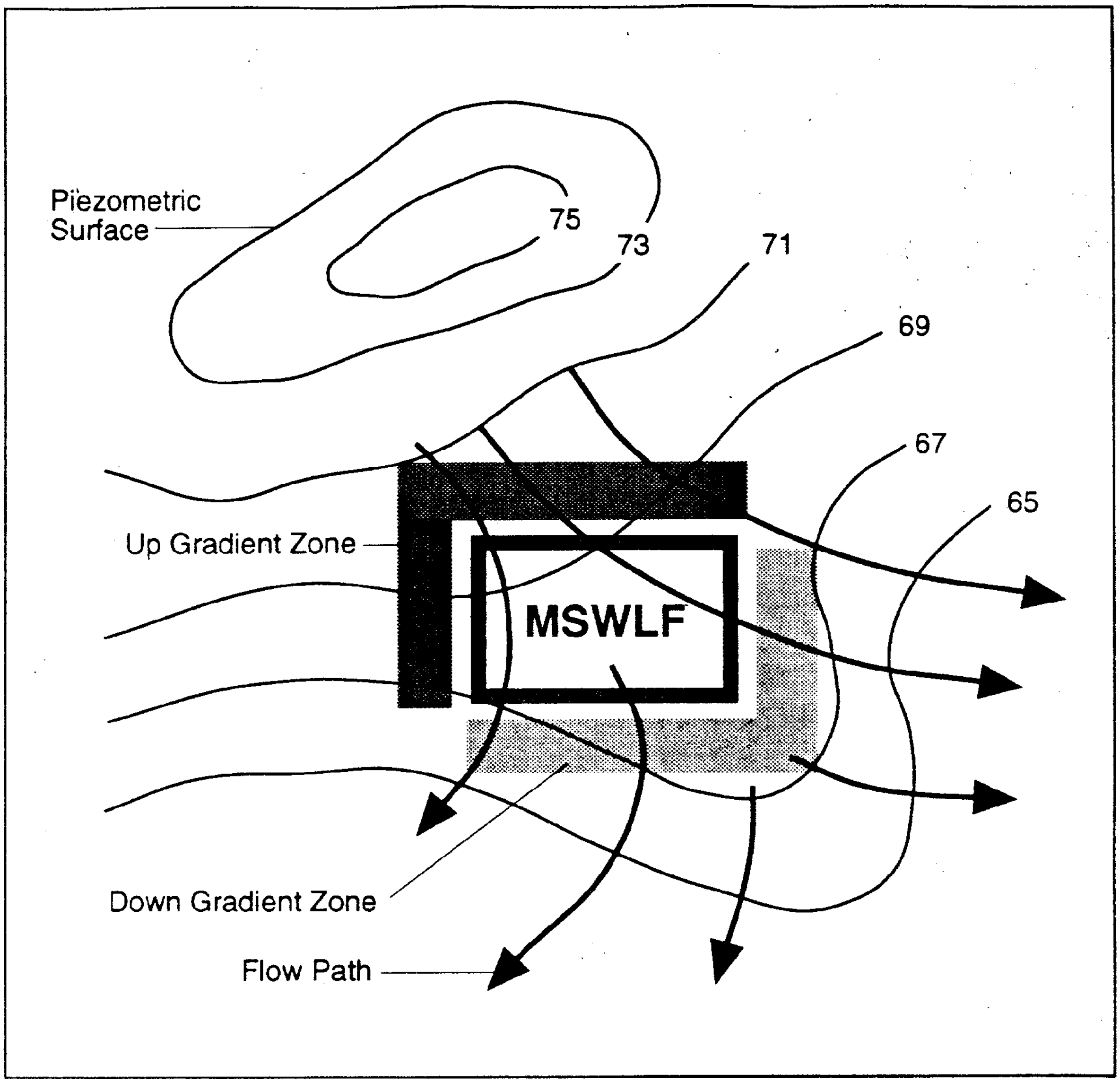


Figure 5-2
Upgradient and Downgradient
Designations for Idealized MSWLF

contaminants may occur as light non aqueous phase liquids (LNAPLs), which are lighter than water, and DNAPLs, which are denser than water. LNAPLs migrate in the capillary zone just above the water table. Wells installed to monitor LNAPLs should be screened at the water table/capillary zone interface, and the screened interval should intercept the water table at its minimum and maximum elevation. LNAPLs may become trapped in residual form in the vadose zone and become periodically remobilized and contribute further to aquifer contamination, either as free phase or dissolved phase contaminants, as the water table fluctuates and precipitation infiltrates the subsurface.

The migration of free-phase DNAPLs may be influenced primarily by the geology, rather than the hydrogeology, of the site. That is, DNAPLs migrate downward through the saturated zone due to density and then migrate by gravity along less permeable geologic units (e.g., the slope of confining units, the slope of clay lenses in more permeable strata, bedrock troughs), even in aquifers with primarily horizontal ground-water flow. Consequently, if wastes disposed at the site are anticipated to exist in the subsurface as a DNAPL, the potential DNAPL should be monitored:

- At the base of the aquifer (immediately above the confining layer)
- In structural depressions (e.g., bedrock troughs) in lower hydraulic conductivity geologic units that act as confining layers
- Along lower hydraulic conductivity lenses and units within units of higher hydraulic conductivity
- "Down-the-dip" of lower hydraulic conductivity units that act as confining layers, both upgradient and downgradient of the waste management area.

Because of the nature of DNAPL migration (i.e., along structural, rather than hydraulic, gradients), wells installed to monitor DNAPLs may need to be installed both upgradient and downgradient of the waste management area. It may be useful to construct a structure contour map of lower permeability strata and identify lower permeability lenses upgradient and downgradient of the unit along which DNAPLs may migrate. The wells can then be located accordingly.

The lengths of well screens used in ground-water monitoring wells can significantly affect their ability to intercept releases of contaminants. The complexity of the hydrogeology of a site is an important consideration when selecting the lengths of well screens. Most hydrogeologic settings are complex (heterogeneous and anisotropic) to a certain degree. Highly heterogeneous formations require shorter well screens to allow sampling of discrete portions of the formation that can serve as contaminant migration pathways. Well screens that span more than a single saturated zone or a single contaminant migration pathway may cause cross-contamination of transmissive units, thereby increasing the extent of contamination. Well intakes should be installed in a single saturated zone. Well intakes (e.g., screens) and filter pack materials should not interconnect, or promote the interconnection of, zones that are separated by a confining layer.

Even in hydrologically simple formations, or within a single potential pathway for contaminant migration, the use of shorter well screens may be necessary to detect contaminants concentrated at particular depths. A contaminant may be concentrated at a particular depth because of its physical/chemical properties and/or because of hydrogeologic properties. In homogeneous formations, a long well screen can permit excessive amounts of uncontaminated formation water to dilute the contaminated ground water entering the well. At best, dilution can make contaminant detection difficult; at worst, contaminant detection is impossible if the concentrations of contaminants are diluted to levels below the detection limits for the prescribed analytical methods. The use of shorter well screens allows for contaminant detection by reducing excessive dilution. When placed at depths of predicted preferential flow, shorter well screens are effective in monitoring the aquifer or the portion of the aquifer of concern.

Generally, screen lengths should not exceed 10 feet. However, certain hydrogeologic settings may warrant or necessitate the use of longer well screens for adequate detection monitoring. Unconfined aquifers with widely fluctuating water tables may require longer screens to intercept the water table surface at both its maximum and minimum elevations and to provide monitoring for the presence of contaminants that are less dense than water. Saturated zones that are slightly greater in thickness than the appropriate screen length (e.g., 12 feet thick) may warrant monitoring with longer screen lengths. Extremely thick homogeneous aquifers (e.g., greater than 300 feet) may be monitored with a longer screen (e.g., a 20-foot screen) because a slightly longer screen would represent a fairly discrete interval in a very thick formation. Formations with very low hydraulic conductivities also may require the use of longer well screens to allow sufficient amounts of formation water to enter the well for sampling. The importance of accurately identifying such conditions highlights the need for a complete hydrogeologic site investigation prior to the design and placement of detection wells.

Multiple monitoring wells (well clusters or multilevel sampling devices) should be installed at a single location when (1) a single well cannot adequately intercept and monitor the vertical extent of a potential pathway of contaminant migration, or (2) there is more than one potential pathway of contaminant migration in the subsurface at a single location, or (3) there is a thick saturated zone and immiscible contaminants are present, or are determined to be potentially present after considering waste types managed at the facility. Conversely, at sites where ground water may be contaminated by a single contaminant, where there is a thin saturated zone, and where the site is hydrogeologically homogeneous, the need for multiple wells at each sampling location is reduced. The number of wells that should be installed at each sampling location increases with site complexity.

The following sources provided additional information on monitoring well placement: USEPA (1992a), USEPA (1990), USEPA (1991), and USEPA (1986a).

5.7 GROUND-WATER MONITORING WELL DESIGN AND CONSTRUCTION 40 CFR §258.51 (c)

5.7.1 Statement of Regulation

(c) Monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of ground-water samples. The annular space (i.e., the space between the bore hole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the ground water.

(1) The owner or operator must notify the State Director that the design, installation, development, and decommission of any monitoring wells, piezometers and other measurement, sampling, and analytical devices documentation has been placed in the operating record; and

(2) The monitoring wells, piezometers, and other measurement, sampling, and analytical devices must be operated and maintained so that they perform to design specifications throughout the life of the monitoring program.

§258.52 [Reserved].

5.7.2 Applicability

The requirements for monitoring well design, installation, and maintenance are applicable to all wells installed at existing units, lateral expansions of units, and new MSWLF units. The design, installation, and decommissioning of any monitoring well must be documented in the operating record of the facility and certified by a qualified ground-water scientist. Documentation is required for wells, piezometers, sampling devices, and water level measurement instruments used in the monitoring program.

The monitoring wells must be cased to protect the integrity of the borehole. The design and construction of the well directly affects the quality and representativeness of the samples collected. The well casing must have a screened or perforated interval to allow the entrance of water into the well casing. The annular space between the well screen and the formation wall must be packed with material to inhibit the migration of formation material into the well. The well screen must have openings sized according to the packing material used. The annular space above the filter pack must be sealed to provide a discrete sampling interval.

All monitoring wells, piezometers, and sampling and analytical devices must be maintained in a manner that ensures their continued performance according to design specifications over the life of the monitoring program.

5.7.3 Technical Considerations

The design, installation, and maintenance of monitoring wells will affect the consistency and accuracy of samples collected. The design must be based on site-specific information. The formation material (lithology and grain size distribution) will determine the selection of proper packing and sealant materials, and the stratigraphy will determine the screen length for the interval to be monitored. Installation practices should be specified and overseen to ensure that the monitoring well is installed as designed and will perform as intended. This section will discuss the factors that must be considered when designing monitoring wells. Each well must be tailored to suit the hydrogeological setting, the contaminants to be monitored, and other site-specific factors. Figure 5-3 depicts the components of a typical monitoring well installation.

The following sections provide a brief overview of monitoring well design and construction. More comprehensive discussions are provided in USEPA (1989f) and USEPA (1992a).

Selection of Drilling Method

The method chosen for drilling a monitoring well depends largely on the following factors (USEPA, 1989f):

- Versatility of the drilling method
- Relative drilling cost
- Sample reliability (ground-water, soil, unconsolidated material, or rock samples)
- Availability of drilling equipment
- Accessibility of the drilling site
- Relative time required for well installation and development
- Ability of the drilling technology to preserve natural conditions
- Ability to install a well of desired diameter and depth
- Relative ease of well completion and development, including the ability to install the well in the given hydrogeologic setting.

In addition to these factors, USEPA (1989f) includes matrices to assist in selecting an appropriate drilling method. These matrices list the most commonly used drilling techniques for monitoring well installation, taking into consideration hydrogeologic settings and the objectives of the monitoring program.

The following basic performance objectives should guide the selection of drilling procedures for installing monitoring wells:

- Drilling should be performed in a manner that preserves the natural properties of the subsurface materials.
- Contamination and/or cross-contamination of ground water and aquifer materials during drilling should be avoided.
- The drilling method should allow for the collection of representative samples of rock, unconsolidated materials, and soil.
- The drilling method should allow the owner/operator to determine when the appropriate location for the screened interval has been encountered.
- The drilling method should allow for proper placement of the filter pack and annular sealants. The borehole should be at least 4 inches larger in diameter than the nominal diameter of the well casing and screen to allow adequate

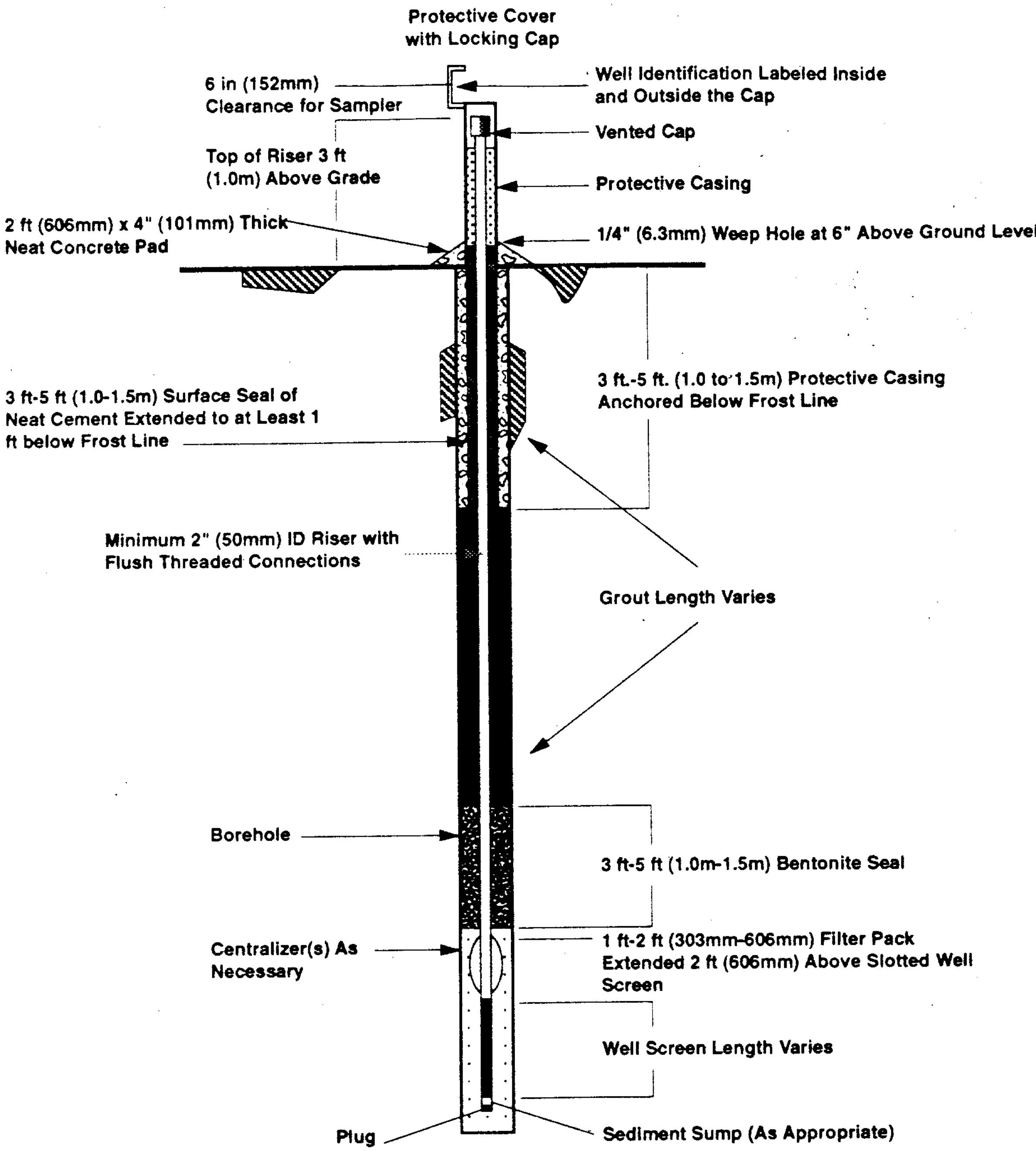


Figure 5.3. Example of a Monitoring Well Design-Single Cased Well

space for placement of the filter pack and annular sealants.

- The drilling method should allow for the collection of representative ground-water samples. Drilling fluids (including air) should be used only when minimal impact to the surrounding formation and ground water can be ensured.

The following guidelines apply to the use of drilling fluids, drilling fluid additives, and lubricants when drilling ground-water monitoring wells:

- Drilling fluids, drilling fluid additives, or lubricants that affect the analysis of hazardous constituents in ground-water samples should not be used.

- The owner/operator should demonstrate the inertness of drilling fluids, drilling fluid additives, and lubricants by performing analytical testing of drilling fluids, drilling fluid additives, and lubricants and/or by providing information regarding the composition of drilling fluids, drilling fluid additives, or lubricants obtained from the manufacturer.

- The owner/operator should consider the potential impact of drilling fluids, drilling fluid additives, and lubricants on the physical and chemical characteristics of the subsurface and on ground-water quality.

- The volume of drilling fluids, drilling fluid additives, and lubricants used during the drilling of a monitoring well should be recorded.

Monitoring Well Design

Well Casing

<u>Well Casing and Screen Materials</u>

A casing and well screen are installed in a ground-water monitoring well for several reasons: to provide access from the surface of the ground to some point in the subsurface, to prevent borehole collapse, and to prevent hydraulic communication between zones within the subsurface. In some cases, State or local regulations may specify the casing and material that the owner or operator should use. A comprehensive discussion of well casing and screen materials is provided in USEPA (1989f) and in USEPA (1992a). The following discussion briefly summarizes information contained in these references.

Monitoring well casing and screen materials may be constructed of any of several types of materials, but should meet the following performance specifications:

- Monitoring well casing and screen materials should maintain their structural integrity and durability in the environment in which they are used over their operating life.

- Monitoring well casings and screens should be resistant to chemical and microbiological corrosion and degradation in contaminated and uncontaminated waters.

- Monitoring well casings and screens should be able to withstand the physical forces acting upon them during and following their installation and during their use -- including forces due to suspension in the borehole, grouting, development, purging, pumping, and sampling and forces exerted on them by the surrounding geologic materials.

- Monitoring well casing and screen materials should not chemically alter ground-water samples, especially with respect to the analytes of concern, as a result of their sorbing, desorbing, or leaching analytes. For example, if chromium is an analyte of interest, the well casing or screen should not increase or decrease the amount of chromium in the ground water. Any material leaching from the casing or screen should not be an analyte of interest or interfere in the analysis of an analyte of interest.

In addition, monitoring well casing and screen materials should be relatively easy to install into the borehole during construction of the monitoring well.

The selection of the most suitable well casing and screen materials should consider site-specific factors, including:

- Depth to the water-bearing zone(s) to be monitored and the anticipated well depth

- Geologic environment

- Geochemistry of soil, unconsolidated material, and rock over the entire interval in which the well is to be cased

- Geochemistry of the ground water at the site, as determined through an initial analysis of samples from both background wells and downgradient wells and including:

  - Natural ground-water geochemistry

  - Nature of suspected or known contaminants

  - Concentration of suspected or known contaminants

- Design life of the monitoring well.

Casing materials widely available for use in ground-water monitoring wells can be divided into three categories:

1) <u>Fluoropolymer materials</u>, including polytetrafluoroethylene (PTFE), tetrafluoroethylene (TFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy (PFA), and polyvinylidene fluoride (PVDF)

2) <u>Metallic materials</u>, including carbon steel, low-carbon steel, galvanized steel, and stainless steel (304 and 316)

3) <u>Thermoplastic materials</u>, including polyvinyl chloride (PVC) and acrylonitrile butadiene styrene (ABS).

In addition to these three categories of materials, fiberglass-reinforced plastic (FRP) has been used for monitoring applications. Because FRP has not yet been used in general application across the country, very little data are available on its characteristics and performance. All well construction materials possess strength-related characteristics and chemical resistance/chemical interference characteristics that influence their performance in site-specific hydrogeologic and contaminant-related monitoring situations.

The casing must be made of a material strong enough to last for the life of the well. Tensile strength is needed primarily during well installation when the casing is lowered into the hole. The joint strength will determine the maximum length of a section that can be suspended from the surface in an air-filled borehole.

Collapse strength is the capability of a casing to resist collapse by any external loads to which it is subjected both during and after installation. A casing is most susceptible to collapse during installation before placement of the filter pack or annular seal materials around the casing. Once a casing is installed and supported, collapse is seldom a concern. Several steps that can be taken to avoid casing collapse are:

1) Drilling a straight, clean borehole

2) Uniformly distributing filter pack materials at a slow, even rate

3) Avoiding use of quick-setting (high temperature) cements for thermoplastic casings installation.

Compressive strength of the casing is a measure of the greatest compressive stress that a casing can bear without deformation. Casing failure due to a compressive strength limitation generally is not an important factor in a properly installed well. This type of failure results from soil friction on unsupported casing.

Chemical resistance/interference characteristics must be evaluated before selecting monitoring well materials. Metallic casing materials are more subject to corrosion, while thermoplastic casing materials are more susceptible to chemical degradation. The geochemistry of the formation water influences the degree to which these processes occur. If ground-water chemistry affects the structural integrity of the casing, then the samples collected from the well are likely to be affected.

Materials used for monitoring well casing must not exhibit a tendency to sorb or leach chemical constituents from, or into, water sampled from the well. If a casing material sorbs constituents from ground water, those constituents may either not be detected during monitoring or be detected at a lower concentration. Chemical constituents also can be leached from the casing materials by aggressive aqueous solutions. These constituents may be detected in samples collected from the well. The results may indicate contamination that is due to the casing rather than the formation water. Casing materials must be selected with care to avoid degradation of the well and to avoid erroneous results.

In certain situations it may be advantageous to design a well using more than one material for well components. For example, where stainless steel or fluoropolymer materials are preferred in a specific chemical environment, costs may be saved by using PVC in non-critical portions of the well. These savings may be considerable, especially in deep wells where only the lower portion of the well is in a critical chemical environment and where tens of feet of lower-cost PVC may be used in the upper portion of the well. In a composite well design, dissimilar metallic components should not be used unless an electrically isolating design is incorporated (i.e., a dielectric coupling) (USEPA, 1986).

Coupling Procedures for Joining Casing

Only a limited number of methods are available for joining lengths of casing or casing and screen together. The joining method depends on the type of casing and type of casing joint.

There are generally two options available for joining metallic well casings: welding via application of heat, or threaded joints. Threaded joints provide inexpensive, fast, and convenient connections and greatly reduce potential problems with chemical resistance or interference (due to corrosion) and explosion potential. Wrapping the male threads with fluoropolymer tape prior to joining sections improves the watertightness of the joint. One disadvantage to using threaded joints is that the tensile strength of the casing string is reduced to approximately 70 percent of the casing strength. This reduction in strength does not usually pose a problem because strength requirements for small diameter wells (such as typical monitoring wells) are not as critical and because metallic casing has a high initial tensile strength.

Joints should create a uniform inner and outer casing diameter in monitoring well installations. Solvent cementing of thermoplastic pipe should never be used in the construction of ground-water monitoring wells. The cements used in solvent welding, which are organic chemicals, have been shown to adversely affect the integrity of ground-water samples for more than 2 years after well installation; only factory-threaded joints should be used on thermoplastic well material.

Well Casing Diameter

Although the diameter of the casing for a monitoring well depends on the purpose of the well, the casing size is generally selected to accommodate downhole equipment. Additional casing diameter selection criteria include the 1) drilling or well installation method used, 2) anticipated depth of the well and associated strength requirements, 3) anticipated method of well development, 4) volume of water required to be purged prior to sampling, 5) rate of recovery of the well after purging, and 6) anticipated aquifer testing.

Casing Cleaning Requirements

Well casing and screen materials should be cleaned prior to installation to remove any coatings or manufacturing residues. Prior to use, all casing and screen materials should be washed with a mild, non-phosphate, detergent/potable water solution and rinsed with potable water. Hot pressurized water, such as in steam cleaning, should be used to remove organic solvents, oils, or lubricants from casing and screens composed of materials other than plastic. At sites where volatile organic contaminants may be monitored, the cleaning of well casing and screen materials should include a final rinse with deionized water or potable water that has not been chlorinated. Once cleaned, casings and screens should be stored in an area that is free of potential contaminants. Plastic sheeting can generally be used to cover the ground in the decontamination area to provide protection from contamination. USEPA (1989f) describes the procedures that should be used to clean casing and screen materials.

Well Intake Design

The owner/operator should design and construct the intakes of monitoring wells to (1) accurately sample the aquifer zone that the well is intended to sample, (2) minimize the passage of formation materials (turbidity) into the well, and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure. The goal of a properly completed monitoring well is to provide low turbidity water that is representative of ground-water quality in the vicinity of the well. Close attention to proper selection of packing materials and well development procedures for wells installed in fine-grained formations (e.g., clays and silty glacial tills) is important to minimize sample turbidity from suspended and colloidal solids. There may be instances where wells completed in rock do not require screens or filter packs; the State regulatory agency should be consulted prior to completion of unscreened wells.

The selection of screen length usually depends on the objective of the well. Piezometers and wells where only a discrete flow path is monitored (such as thin gravel interbedded with clays) are generally completed using short screens (2 feet or less). To avoid dilution, the well screens should be kept to the minimum length appropriate for intercepting a contaminant plume, especially in a high-yielding aquifer. The screen length should generally not exceed 10 feet. If construction of a water table well is the objective, either for defining gradient or detecting floating phases, then a longer screen is acceptable because the owner/operator will need to provide a margin of safety that will guarantee that at least a portion of the screen always contacts the water table regardless of its seasonal fluctuations. The owner or operator should not employ well intake designs that cut across hydraulically separated geologic units.

Well screen slot size should be selected to retain from 90 percent to 100 percent of the filter pack material (discussed below) in artificially filter packed wells. Well screens should be factory-slotted. Manual slotting of screens in the field should not be performed under any circumstances.

Filter Pack Design

The primary filter pack material should be a chemically inert material and well rounded, with a high coefficient of uniformity. The best filter pack materials are made from industrial grade glass (quartz) sand or beads. The use of other materials, such as local, naturally occurring clean sand, is discouraged unless it can be shown that the material is inert (e.g., low cation exchange capacity), coarse-grained, permeable, and uniform in grain size. The filter pack should extend at least 2 feet above the screened interval in the well.

Although design techniques for selecting filter pack size vary, all use the filter pack ratio to establish size differential between formation materials and filter pack materials. Generally, this ratio refers to either the average (50 percent retained) grain size of the formation material or to the 70 percent retained size of the formation material. Barcelona et al. (1985b) recommend using a uniform filter pack grain size that is three to five times the size of the 50 percent retained size of the formation material (USEPA, 1990).

Filter pack material should be installed in a manner that prevents bridging and particle-size segregation. Filter pack material installed below the water table should generally be tremied into the annular space. Allowing filter pack material to fall by gravity (free fall) into the annular space is only appropriate when wells are relatively shallow, when the filter pack has a uniform grain size, and when the filter pack material can be poured continuously into the well without stopping.

At least 2 inches of filter pack material should be installed between the well screen and the borehole wall. The filter pack should extend at least 2 feet above the top of the well screen. In deep wells, the filter pack may not compress when initially installed. Consequently, when the annular and surface seals are placed on the filter pack, the filter pack compresses sufficiently to allow grout into, or very close to, the screen. Consequently, filter packs may need to be installed as high as 5 feet above the screened interval in monitoring wells that are deep (i.e., greater than 200 feet). The precise volume of filter pack material required should be calculated and recorded before placement, and the actual volume used should be determined and recorded during well construction. Any significant discrepancy between the calculated volume and the actual volume should be explained.

Prior to installing the annular seal, a 1- to 2-foot layer of chemically inert fine sand may be placed over the filter pack to prevent the intrusion of annular or surface sealants into the filter pack. When designing monitoring wells, owners and operators should remember that the entire length of the annular space filled with filter pack material or sand is effectively the monitored zone. Moreover, if the filter pack/sand extends from the screened zone into an overlying zone, a conduit for hydraulic connection is created between the two zones.

Annular Sealants

Proper sealing of the annular space between the well casing and the borehole wall is required to prevent contamination of samples and the ground water. Adequate sealing will prevent hydraulic connection within the well annulus. The materials used for annular sealants should be chemically inert with the highest anticipated concentration of chemical constituents expected in the ground water at the facility. In general, the permeability of the sealing material should be one to two orders of magnitude lower than the least permeable part of the formation in contact with the well. The precise volume of annular sealants required should be calculated and recorded before placement, and the actual volume used should be determined and recorded during well construction. Any significant discrepancy between the calculated volume and the actual volume should be explained.

When the screened interval is within the saturated zone, a minimum of 2 feet of sealant material, such as raw (>10 percent solids) bentonite, should be placed immediately over the protective sand layer overlying the filter pack. Granular bentonite, bentonite pellets, and bentonite chips may be placed around the casing by means of a tremie pipe in deep wells (greater than approximately 30 feet deep), or by dropping them directly down the annulus in shallow wells (less than approximately 30 feet deep). Dropping the bentonite pellets down the annulus presents a potential for bridging (from premature hydration of the bentonite), leading to gaps in the seal below the bridge. In shallow monitoring wells, a tamping device should be used to prevent bridging from occurring.

A neat cement or shrinkage-compensated neat cement grout seal should be installed on top of the bentonite seal and extend vertically up the annular space between the well casing and the borehole wall to within a few feet of land surface. Annular sealants in slurry form (e.g., cement grout, bentonite slurry) should be placed by the tremie/pump (from the bottom up) method. The bottom of the placement pipe should be equipped with a side discharge deflector to prevent the slurry from jetting a hole through the protective sand layer, filter pack, or bentonite seal. The bentonite seal should be allowed to completely hydrate, set, or cure in conformance with the manufacturer's specifications prior to installing the grout seal in the annular space. The time required for the bentonite seal to completely hydrate, set, or cure will differ with the materials used and the specific conditions encountered, but is generally a minimum of 4 to 24 hours. Allowing the bentonite seal to hydrate, set, or cure prevents the invasion of the more viscous and more chemically reactive grout seal into the screened area.

When using bentonite as an annular sealant, the appropriate clay should be selected on the basis of the environment in which it is to be used, such as the ion-exchange potential of the sediments, sediment permeability, and compatibility with expected contaminants. Sodium bentonite is usually acceptable.

When the annular sealant must be installed in the unsaturated zone, neat cement or shrinkage-compensated neat cement mixtures should be used for the annular sealant. Bentonite is not recommended as an annular sealant in the unsaturated zone because the moisture available is insufficient to fully hydrate bentonite.

Surface Completion

Monitoring wells are commonly either above-ground completions or flush-to-ground completions. The design of both types must consider the prevention of infiltration of surface runoff into the well annulus and the possibility of accidental damage or vandalism. Completing a monitoring well involves installing the following components:

- Surface seal
- Protective casing
- Ventilation hole
- Drain hole
- Cap and lock
- Guard posts when wells are completed above grade.

A surface seal, installed on top of the grout seal, extends vertically up the well annulus to the land surface. To protect against frost heave, the seal should extend at least 1 foot below the frost line. The composition of the surface seal should be neat cement or concrete. In an above-ground completion, the surface seal should form at least a 2-foot wide, 4-inch thick apron.

A locking protective casing should be installed around the well casing to prevent damage or unauthorized entry. The protective casing should be anchored below the frost line (where applicable) into the surface seal and extend at least 18 inches above the surface of the ground. A 1/4-inch vent hole pipe is recommended to allow the escape of any potentially explosive gases that may accumulate within the well. In addition, a drain hole should be installed in the protective casing to prevent water from accumulating and, in freezing climates, freezing around the well casing. The space between the protective casing and the well casing may be filled with gravel to allow the retrieval of tools and to prevent small animal/insect entrance through the drain. A suitable cap should be placed on the well to prevent tampering or the entry of any foreign materials. A lock should be installed on the cap to provide security. To prevent corrosion or jamming of the lock, a protective cover should be used. Care should be taken when using such lubricants as graphite or petroleum-based sprays to lubricate the lock, as lubricants may introduce a potential for sample contamination.

To guard against accidental damage to the well from facility traffic, the owner/operator should install concrete or steel bumper guards around the edge of the concrete apron. These should be located within 3 or 4 feet of the well and should be painted orange or fitted with reflectors to reduce the possibility of vehicular damage.

The use of flush-to-ground surface completions should be avoided because this design increases the potential for surface water infiltration into the well. In cases where flush-to-ground completions are unavoidable, such as in active roadways, a protective structure, such as a utility vault or meter box, should be installed around the well casing. In addition, measures should be taken to prevent the accumulation of surface water in the protective structure and around the well intake. These measures should include outfitting the protective structure with a steel lid or manhole cover that has a rubber seal or gasket and ensuring that the bond between the cement surface seal and the protective structure is watertight.

Well Surveying

The location of all wells should be surveyed by a licensed professional surveyor (or equivalent) to determine their X-and-Y coordinates as well as their distances from the units being monitored and their distances from each other. A State Plane Coordinate System, Universal Transverse Mercator System, or Latitude/Longitude should be used, as approved by the Regional Administrator. The survey should also note the coordinates of any temporary benchmarks. A surveyed reference mark should be placed on the top of the well casing, not on the protective casing or the well apron, for use as a measuring point because the well casing is more stable than the protective casing or well apron (both the protective casing and the well apron are more susceptible to frost heave and spalling). The height of the reference survey datum, permanently marked on top of the inner well casing, should be determined within ±0.01 foot in relation to mean sea level, which in turn is determined by reference to an established National Geodetic Vertical Datum. The reference marked on top of inner well casings should be resurveyed at least once every 5 years, unless changes in ground-water flow patterns/direction, or damage caused by freeze/thaw or desiccation processes, are noted. In such cases, the Regional Administrator may require that well casings be resurveyed on a more frequent basis.

Well Development

All monitoring wells should be developed to create an effective filter pack around the well screen, to rectify damage to the formation caused by drilling, to remove fine particles from the formation near the borehole, and to assist in restoring the natural water quality of the aquifer in the vicinity of the well. Development stresses the formation around the screen, as well as the filter pack, so that mobile fines, silts, and clays are pulled into the well and removed. The process of developing a well creates a graded filter pack around the well screen. Development is also used to remove any foreign materials (drilling water, muds, etc.) that may have been introduced into the well borehole during drilling and well installation and to aid in the equilibration that will occur between the filter pack, well casing, and the formation water.

The development of a well is extremely important to ensuring the collection of representative ground-water samples. If the well has been properly completed, then adequate development should remove fines that may enter the well either from the filter pack or the formation. This improves the yield, but more importantly it creates a monitoring well capable of producing samples of acceptably low turbidity. Turbid samples from an improperly constructed and developed well may interfere with subsequent analyses.

When development is initiated, a wide range of grain sizes of the natural material is drawn into the well, and the well typically produces very turbid water. However, as development continues and the natural materials are drawn into the filter pack, an effective filter will form through a sorting process. Inducing movement of ground water into the well (i.e., in one direction) generally results in bridging of the particles. A means of inducing flow reversal is necessary to break down bridges and produce a stable filter.

The commonly accepted methods for developing wells are described in USEPA (1989f) and Driscoll (1986) and include:

- Pumping and overpumping
- Surging with a surge block
- Bailing.

USEPA (1989f) provides a detailed overview of well development and should be consulted when evaluating well development methods.

Documentation of Well Design, Construction, and Development

Information on the design, construction, and development of each well should be compiled. Such information should include (1) a boring log that documents well drilling and associated formation sampling and (2) a well construction log and well construction diagram ("as built").

Decommissioning Ground-Water Monitoring Wells and Boreholes

Ground-water contamination resulting from improperly decommissioned wells and boreholes is a serious concern. Any borehole that will not be completed as a monitoring well should be properly decommissioned. The USEPA (1975) and the American Water Works Association (1985) provide the following reasons, summarized by USEPA (1989f), as to why improperly constructed or unused wells should be properly decommissioned:

- To eliminate physical hazards
- To prevent ground-water contamination
- To conserve aquifer yield and hydrostatic head
- To prevent intermixing of subsurface water.

Should an owner or operator have a borehole or an improperly constructed or unused well at his or her facility, the well or borehole should be decommissioned in accordance with specific guidelines. USEPA (1989f) provides comprehensive guidance on performing well decommissioning that can be applied to boreholes. In addition, any State/Tribal regulatory guidance should be consulted prior to decommissioning monitoring wells, piezometers, or boreholes. Lamb and Kinney (1989) also provide information on decommissioning ground-water monitoring wells.

Many States require that specific procedures be followed and certain paperwork be filed when decommissioning water supply wells. In some States, similar regulations may apply to the decommissioning of monitoring wells and boreholes. The EPA and other involved regulatory agencies, as well as experienced geologists, geotechnical engineers, and drillers, should be consulted prior to decommissioning a well or borehole to ensure that decommissioning is performed properly and to ensure compliance with State law. If a well to be decommissioned is contaminated, the safe removal and proper disposal of the well materials should be ensured by the owner/operator. Appropriate measures should be taken to protect the health and safety of individuals when decommissioning a well or borehole.

5.8 GROUND-WATER SAMPLING AND ANALYSIS REQUIREMENTS 40 CFR §258.53

5.8.1 Statement of Regulation

(a) The ground-water monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of ground-water quality at the background and downgradient wells installed in compliance with §258.51(a) of this Part. The owner or operator must notify the State Director that the sampling and analysis program documentation has been placed in the operating record and the program must include procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures;

(4) Chain of custody control; and

(5) Quality assurance and quality control.

(b) The ground-water monitoring program must include sampling and analytical methods that are appropriate for ground-water sampling and that accurately measure hazardous constituents and other monitoring parameters in ground-water samples. Ground-water samples shall not be field-filtered prior to laboratory analysis.

(c) The sampling procedures and frequency must be protective of human health and the environment.

(d) Ground-water elevations must be measured in each well immediately prior to purging, each time ground water is sampled. The owner or operator must determine the rate and direction of ground-water flow each time ground water is sampled. Ground-water elevations in wells which monitor the same waste management area must be measured within a period of time short enough to avoid temporal variations in ground-water flow which could preclude accurate determination of ground-water flow rate and direction.

(e) The owner or operator must establish background ground-water quality in a hydraulically upgradient or background well(s) for each of the monitoring parameters or constituents required in the particular ground-water monitoring program that applies to the MSWLF unit, as determined under §258.54(a), or §258.55(a) of this Part. Background ground-water quality may be established at wells that are not located hydraulically upgradient from the MSWLF unit if it meets the requirements of §258.51(a)(1).

(f) The number of samples collected to establish ground-water quality data must be consistent with the appropriate statistical procedures determined pursuant to paragraph (g) of this section. The sampling procedures shall be those specified under §258.54(b) for detection monitoring, §258.55(b) and (d) for assessment monitoring, and §258.56(b) of corrective action.

<u>5.8.2 Applicability</u>

The requirements for sampling and analysis apply to all facilities required to conduct ground-water monitoring throughout the active life, closure, and post-closure periods of operation. Quality assurance and quality control measures for both field and laboratory activities must be implemented. The methods and procedures constituting the program must be placed in the operating record of the facility.

For the sampling and analysis program to be technically sound, the sampling procedures and analytical methods used should provide adequate accuracy, precision, and detection limits for the analyte determinations. Prior to sampling, the static ground-water elevations in the wells must be measured to allow determination of the direction of ground-water flow and estimates of rate of flow. The time interval between measurements at different wells must be minimized so that temporal changes in ground-water elevations do not cause an incorrect determination of ground-water flow direction.

Background ground-water quality must be established at all upgradient or background wells. The background water quality may be determined from wells that are not upgradient of the MSWLF unit, provided that the wells yield representative ground-water samples.

The sampling program must be designed in consideration of the anticipated statistical method applied by the owner or operator. The data objectives of the monitoring program, in terms of the number of samples collected and the frequency of collection, should be appropriate for the statistical method selected for data comparison.

5.8.3 Technical Considerations

The purpose of a ground-water sampling and analysis program is to establish a protocol that can be followed throughout the monitoring period of the site (operating, closure, and post-closure). The protocol is necessary so that data acquired can be compared over time and accurately represent ground-water quality. Sample collection, preservation, shipment, storage, and analyses should always be performed in a consistent manner, even as monitoring staff change during the monitoring period.

The owner's/operator's ground-water monitoring program must include a description of procedures for the following:

- Sample collection
- Sample preservation and shipment
- Analytical procedures
- Chain of custody control
- Quality assurance and quality control.

The ground-water monitoring program must be documented in the operating record of the facility.

The objectives of the monitoring program should clearly define the quality of the data required to detect significant changes in ground-water chemistry due to the operation of the solid waste disposal facility. These data quality objectives should address:

- Accuracy and precision of methods used in the analysis of samples, including field measurements
- Quality control and quality assurance procedures used to ensure the validity of the results (e.g., use of blank samples, record keeping, and data validation)
- Number of samples required to obtain a certain degree of statistical confidence
- Location and number of monitoring wells required.

Sample Collection

Frequency

The frequency of sample collection under detection monitoring should be evaluated for each site according to hydrogeologic conditions and landfill design. In States, the minimum sampling frequency should be semiannual. The background characterization should include four independent samples at each monitoring location during the first semi-annual event (i.e., during the first 6 months of monitoring). (See the discussion under Section 5.10.3 on collecting independent samples to determine background.) More frequent sampling may be selected. For example, quarterly sampling may be conducted to evaluate seasonal effects on ground-water quality.

The frequency of sample collection during assessment monitoring activities will depend on site-specific hydrogeologic conditions and contaminant properties. The frequency of sampling is intended to obtain a data set that is statistically independent of the previous set. Guidance to estimate this minimum time to obtain independent samples is provided in "Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities - Interim Final Guidance" (USEPA, 1989).

Water Level Measurements

The ground-water monitoring program must include provisions for measuring static water level elevations in each well prior to purging the well for sampling. Measurements of ground-water elevations are used for determining horizontal and vertical hydraulic gradients for estimation of flow rates and direction.

Field measurements may include the following:

- Depth to standing water from a surveyed datum on the top of the well riser (static water level)
- Total depth of well from the top of the riser (to verify condition of well)
- Thickness of immiscible layers, if present.

Measurements of the static water level and the depth to the well bottom can be made with a wetted steel tape. Electronic water level measuring devices may also be used. Accepted standard operating procedures call for the static water level to be accurately measured to within 0.01 foot (USEPA, 1992a). Water level measurements should be made at all monitoring wells and well clusters in a time frame that avoids changes that may occur as a result of barometric pressure changes, significant infiltration events, or aquifer pumping. To prevent possible cross contamination of wells, water level measurement devices must be decontaminated prior to use at each well.

The ground-water monitoring program should include provisions for detecting immiscible fluids (i.e., LNAPLs or DNAPLs). LNAPLs are relatively immiscible liquids that are less dense than water and that spread across the water table surface. DNAPLs are relatively immiscible liquids that are more dense than the ground water and tend to migrate vertically downward in aquifers. The detection of an immiscible layer may require specialized equipment and should be performed before the well is evacuated for conventional sampling. The ground-water monitoring program should specify how DNAPLs and LNAPLs will be detected. The program also should include a contingency plan describing procedures for sampling and analyzing these liquids. Guidance for detecting the presence of immiscible layers can be found in USEPA (1992a).

Well Purging

Because the water standing in a well prior to sampling may not represent in-situ ground-water quality, stagnant water should be purged from the well and filter pack prior to sampling. The QAPjP should include detailed, step-by-step procedures for purging wells, including the parameters that will be monitored during purging and the equipment that will be used for well purging.

Purging should be accomplished by removing ground water from the well at low flow rates using a pump. The use of bailers to purge monitoring wells generally should be avoided. Research has shown that the "plunger" effect created by continually raising and lowering the bailer into the well can result in continual development or overdevelopment of the well. Moreover, the velocities at which ground water enters a bailer can actually correspond to unacceptably high purging rates (Puls and Powell, 1992; Barcelona et al., 1990).

The rate at which ground water is removed from the well during purging ideally should be approximately 0.2 to 0.3 L/min or less (Puls and Powell, 1992; Puls et al., 1991; Puls and Barcelona, 1989a; Barcelona, et al., 1990). Wells should be purged at rates below those used to develop the well to prevent further development of the well, to prevent damage to the well, and to avoid disturbing accumulated corrosion or reaction products in the well (Kearl et al., 1992; Puls et al., 1990; Puls and Barcelona, 1989a; Puls and Barcelona, 1989b; Barcelona, 1985b). Wells also should be purged at or below their recovery rate so that migration of water in the formation above the well screen does not occur. A low purge rate also will reduce the possibility of stripping VOCs from the water, and will reduce the likelihood of mobilizing colloids in the subsurface that are immobile under natural flow conditions. The owner/operator should ensure that purging does not cause formation water to cascade down the sides of the well screen. At no time should a well be purged to dryness if recharge causes the formation water to cascade down the sides of the screen, as this will cause an accelerated loss of volatiles. This problem should be anticipated; water should be purged from the well at a rate that does not cause recharge water to be excessively agitated. Laboratory experiments have shown that unless cascading is prevented, up to 70 percent of the volatiles present could be lost before sampling.

To eliminate the need to dispose of large volumes of purge water, and to reduce the amount of time required for purging, wells may be purged with the pump intake just above or just within the screened interval. This procedure eliminates the need to purge the column of stagnant water located above the well screen (Barcelona et al., 1985b; Robin and Gillham, 1987; Barcelona, 1985b; Kearl et al., 1992). Purging the well at the top of the well screen should ensure that fresh water from the aquifer moves through the well screen and upward within the screened interval. Pumping rates below the recharge capability of the aquifer must be maintained if purging is performed with the pump placed at the top of the well screen, below the stagnant water column above the top of the well screen (Kearl et al., 1992). The Agency suggests that a packer be placed above the screened interval to ensure that "stagnant" casing water is not drawn into the pump. The packer should be kept inflated in the well until after ground-water samples are collected.

In certain situations, purging must be performed with the pump placed at, or immediately below, the air/water interface.

If a bailer must be used to sample the well, the well should be purged by placing the pump intake immediately below the air/water interface. This will ensure that all of the water in the casing and filter pack is purged, and it will minimize the possibility of mixing and/or sampling stagnant water when the bailer is lowered down into the well and subsequently retrieved (Keeley and Boateng, 1987). Similarly, purging should be performed at the air/water interface if sampling is not performed immediately after the well is purged without removing the pump. Pumping at the air/water interface will prevent the mixing of stagnant and fresh water when the pump used to purge the well is removed and then lowered back down into the well for the purpose of sampling.

In cases where an LNAPL has been detected in the monitoring well, special procedures should be used to purge the well. These procedures are described in USEPA (1992a).

For most wells, the Agency recommends that purging continue until measurements of turbidity, redox potential, and dissolved oxygen in in-line or downhole analyses of ground water have stabilized within approximately 10% over at least two measurements (Puls and Powell, 1992; Puls and Eychaner, 1990; Puls et al., 1990; Puls and Barcelona, 1989a; Puls and Barcelona, 1989b; USEPA, 1991; Barcelona et al., 1988b). If a well is purged to dryness or is purged such that full recovery exceeds two hours, the well should be sampled as soon as a sufficient volume of ground water has entered the well to enable the collection of the necessary ground-water samples.

All purging equipment that has been or will be in contact with ground water should be decontaminated prior to use. If the purged water or the decontamination water is contaminated (e.g., based on analytical results), the water should be stored in appropriate containers until analytical results are available, at which time proper arrangements for disposal or treatment should be made (i.e., contaminated purge water may be a hazardous waste).

Field Analyses

Several constituents or parameters that owners or operators may choose to include in a ground-water monitoring program may be physically or chemically unstable and should be tested after well purging and before the collection of samples for laboratory analysis. Examples of unstable parameters include pH, redox (oxidation-reduction) potential, dissolved oxygen, temperature, and specific conductance.

Field analyses should not be performed on samples designated for laboratory analysis. Any field monitoring equipment or field-test kits should be calibrated at the beginning of each use, according to the manufacturers' specifications and consistent with methods in SW-846 (USEPA, 1986b).

Sample Withdrawal and Collection

The equipment used to withdraw a ground-water sample from a well must be selected based on consideration of the parameters to be analyzed in the sample. To ensure the sample is representative of ground water in the formation, it is important to keep physical or chemical alterations of the sample to a minimum. USEPA (1992a) provides an overview of the issues involved in selecting ground-water sampling equipment, and a summary of the application and limitations of various sampling mechanisms. Sampling materials and equipment should be selected to preserve sample integrity. Sampling equipment should be constructed of inert material. Sample collection equipment should not alter analyte concentrations, cause loss of analytes via sorption, or cause gain of analytes via desorption, degradation, or corrosion. Sampling equipment should be designed such that Viton®, Tygon®, silicone, or neoprene components do not come into contact with the ground-water sample. These materials have been demonstrated to cause sorptive losses of contaminants (Barcelona et al., 1983; Barcelona et al., 1985b; Barcelona et al., 1988b; Barcelona et al., 1990). Barcelona (1988b) suggests that sorption of volatile organic compounds on silicone, polyethylene, and PVC tubing may result in gross errors when determining concentrations of trace organics in ground-water samples. Barcelona (1985b) discourages the use of PVC sampling equipment when sampling for organic contaminants. Fluorocarbon resin (e.g., Teflon®) or stainless steel sampling devices which can be easily disassembled for thorough decontamination are widely used. Dedicating sampling equipment to each monitoring well will help prevent cross-contamination problems that could arise from improper decontamination procedures.

Sampling equipment should cause minimal sample agitation and should be selected to reduce/eliminate sample contact with the atmosphere during sample transfer. Sampling equipment should not allow volatilization or aeration of samples to the extent that analyte concentrations are altered.

Bladder pumps are generally recognized as the best overall sampling device for both organic and inorganic constituents, although other types of pumps (e.g., low-rate submersible centrifugal pumps, helical rotor electric submersible pumps) have been found suitable in some applications. Bailers, although inexpensive and simple to use, have been found to cause volatilization of samples, mobilization of particulates in wells and imprecise results (USEPA, 1992a).

The following recommendations apply to the use and operation of ground-water sampling equipment:

- Check valves should be designed and inspected to ensure that fouling problems do not reduce delivery capabilities or result in aeration of samples.

- Sampling equipment should never be dropped into the well, as this will cause degassing of the water upon impact.

- Contents of the sampling device should be transferred to sample containers in a controlled manner that will minimize sample agitation and aeration.

- Decontaminated sampling equipment should not be allowed to come into contact with the ground or other contaminated surfaces prior to insertion into the well.

- Ground-water samples should be collected as soon as possible after the well is purged. Water that has remained in the well casing for more than about 2 hours has had the opportunity to exchange gases with the atmosphere and to interact with the well casing material (USEPA, 1991b).

- The rate at which a well is sampled should not exceed the rate at which the well was purged. Low sampling rates, approximately 0.1 L/min, are suggested. Low sampling rates will help to ensure that particulates, immobile in the subsurface under ambient conditions, are not entrained in the sample and that volatile compounds are not stripped from the sample (Puls and Barcelona, 1989b; Barcelona, et al., 1990; Puls et al., 1991; Kearl et al., 1992; USEPA, 1991b). Pumps should be operated at rates less than 0.1 L/min when collecting samples for volatile organics analysis.

- Pump lines should be cleared at a rate of 0.1 L/min or less before collecting samples for volatiles analysis so that the samples collected will not be from the period of time when the pump was operating more rapidly.

- Pumps should be operated in a continuous manner so that they do not produce samples that are aerated in the return tube or upon discharge.

- When sampling wells that contain LNAPLs, a stilling tube should be inserted in the well. Ground-water samples should be collected from the screened interval of the well below the base of the tube.

- Ground-water samples collected for analysis for organic constituents or parameters should not be filtered in the field.

Once appropriate sampling equipment has been selected and operating procedures established, samples should be collected and containerized in the order of the volatilization sensitivity of the parameter. The preferred collection order for some of the more common ground-water analytes is depicted on the flow chart shown in Figure 5-4.

The ground-water monitoring program documentation should include explicit procedures for disassembly and decontamination of sampling equipment before each use. Improperly decontaminated equipment can affect samples in several ways. For example, residual contamination from the previous well may remain on equipment, or improper decontamination may not remove all of the detergents or solvents used during decontamination. Specific guidance regarding decontamination of the sampling equipment is available (USEPA 1992a). To keep sample cross-contamination to a minimum, sampling should proceed from upgradient or background locations to downgradient locations that would contain higher concentrations of contaminants.

Sample Preservation and Handling

The procedures for preserving and handling samples are nearly as important for ensuring the integrity of the samples as the collection device itself. Detailed procedures for sample preservation must be provided in the Quality Assurance Project Plan (QAPjP) that is included in the sampling and analysis program description.

STEP	*PROCEDURE*	*ESSENTIAL ELEMENTS*
Well Inspection	Hydrologic Measurements ↓	Water Level Measurements
Well Purging	Removal or Isolation of Stagnant Water ↓	Representative Water Access
	Determination of Well-Purging Parameters (pH, Eh, -π, Ω)* ↓	Verification of Representative Water Sample Access
Sample Collection** Field Determinations*		Sample Collection by Appropriate Mechanism Minimal Sample Handling
	Volatile Organics, TOX ↓	Head-Space Free Samples
	Dissolved Gases, TOC ↓	Head Space Free Samples
	Large Volume Samples for Organic Compound Determinations ↓	Minimal Aeration or Depressurization
	Metal Samples Cyanides ↓	Adequate Rinsing against Contamination
Preservation Field Blanks Standards	Assorted Sensitive Inorganic Species NO_2^-, NH_4^+, Fe(II) ↓	
	Major Cations and Anions ↓	
	(as needed for good QA/QC)	Minimal Air Contact, Preservation
Storage Transport		Minimal Loss of Sample Integrity Prior to Analysis

* Denotes analytical determinations which should be made in the field.
** This is a suggested order for sampling, not all parameters are required by Part 258.

Figure 5-4
Generalized Flow Diagram of Ground-Water Sampling Steps

Sample Containers

To avoid altering sample quality, the samples should be transferred from the sampling equipment directly into a prepared container. Proper sample containers for each constituent or group of constituents are identified in SW-846 (USEPA, 1986b). Samples should never be composited in a common container in the field and then split. Sample containers should be cleaned in a manner that is appropriate for the constituents to be analyzed. Cleaning procedures are provided by USEPA (1986b). Sample containers that have been cleaned according to these procedures can be procured commercially.

Most vendors will provide a certification of cleanliness.

Sample Preservation

During ground-water sampling, every attempt should be made to minimize changes in the chemistry of the samples. To assist in maintaining the natural chemistry of the samples, it is necessary to preserve the sample. The owner or operator should refer to SW-846 (USEPA, 1986b) for the specific preservation method and holding times for each constituent to be analyzed. Methods of sample preservation are relatively limited and are intended to retard chemical reactions, such as oxidation, retard, biodegradation, and to reduce the effects of sorption. Preservation methods are generally limited to pH control, refrigeration, and protection from light.

Sample Storage and Shipment

The storage and transport of ground-water samples must be performed in a manner that maintains sample quality. Samples should be cooled to 4°C as soon as possible after they are collected. These conditions should be maintained until the samples are received at the laboratory. Sample containers generally are packed in picnic coolers or special containers for shipment.

Polystyrene foam, vermiculite, and "bubble pack" are frequently used to pack sample containers to prevent breakage. Ice is placed in sealed plastic bags and added to the cooler. All related paperwork is sealed in a plastic bag and taped to the inside top of the cooler. The cooler top is then taped shut. Custody seals should be placed across the hinges and latches on the outside of the cooler.

Transportation arrangements should maintain proper storage conditions and provide for effective sample pickup and delivery to the laboratory. Sampling plans should be coordinated with the laboratory so that appropriate sample receipt, storage, analysis, and custody arrangements can be provided.

Most analyses must be performed within a specified period (holding time) from sample collection. Holding time refers to the period that begins when the sample is collected from the well and ends with its extraction or analysis. Data from samples not analyzed within the recommended holding times should be considered suspect. Some holding times for Appendix I constituents are as short as 7 days. To provide the laboratory with operational flexibility in meeting these holding times, samples usually are shipped via overnight courier. Laboratory capacity or operating hours may influence sampling schedules. Coordination with laboratory staff during planning and sampling activities is important in maintaining sample and analysis quality.

The documentation that accompanies samples during shipment to the laboratory usually includes chain-of-custody (including a listing of all sample containers), requested analyses, and full identification of the origin of samples (including contact names, phone numbers, and addresses). Copies of all documents shipped with the samples should be retained by the sampler.

Chain-of-Custody Record

To document sample possession from the time of collection, a chain-of-custody record should be filled out to accompany every sample shipment. The record should contain the following types of information:

- Sample number
- Signature of collector
- Date and time of collection
- Media sampled (e.g., ground water)
- Sample type (e.g., grab)
- Identification of sampling location/well
- Number of containers
- Parameters requested for analysis
- Signatures of persons involved in the chain of possession
- Inclusive dates of possession with time in 24-hour notation
- Internal temperature of shipping container when samples were sealed into the container for shipping
- Internal temperature of container when opened at the laboratory
- Any remarks regarding potential hazards or other information the laboratory may need.

An adequate chain-of-custody program allows for tracing the possession and handling of individual samples from the time of collection through completion of laboratory analysis. A chain-of-custody program should include:

- Sample labels to prevent misidentification of samples
- Sample custody seals to preserve the integrity of the samples from the time they are collected until they are opened in the laboratory
- Field notes to record information about each sample collected during the ground-water monitoring program
- Chain-of-custody record to document sample possession from the time of collection to analysis
- Laboratory storage and analysis records, which are maintained at the laboratory and which record pertinent information about the sample.

Sample Labels

Each sample's identification should be marked clearly in waterproof ink on the sample container. To aid in labeling, the information should be written on each container prior to filling with a sample. The labels should be sufficiently durable to remain legible even when wet and should contain the following information:

- Sample identification number
- Name and signature of the sampler
- Date and time of collection
- Sample location
- Analyses requested.

Sample Custody Seal

Sample custody seals should be placed on the shipping container and/or individual sample bottle in a manner that will break the seal if the container or sample is tampered with.

Field Logbook

To provide an account of all activities involved in sample collection, all sampling activities, measurements, and observations should be noted in a field log. The information should include visual appearance (e.g., color, turbidity, degassing, surface film), odor (type, strength), and field measurements and calibration results. Ambient conditions (temperature, humidity, wind, precipitation) and well purging and sampling activities should also be recorded as an aid in evaluating sample analysis results.

The field logbook should document the following:

- Well identification
- Well depth
- Static water level depth and measurement technique
- Presence and thickness of immiscible layers and the detection method
- Well yield (high or low) and well recovery after purging (slow, fast)
- Well purging procedure and equipment
- Purge volume and pumping rate
- Time well purged
- Collection method for immiscible layers
- Sample withdrawal procedure and equipment
- Date and time of sample collection
- Results of field analysis
- Well sampling sequence
- Types of sample bottles used and sample identification numbers
- Preservatives used
- Parameters requested for analysis
- Field observations of sampling event
- Name of collector
- Weather conditions, including air temperature

- Internal temperature of field and shipping containers.

Sample Analysis Request Sheet

A sample analysis request sheet should accompany the sample(s) to the laboratory and clearly identify which sample containers have been designated for each requested parameter and the preservation methods used. The record should include the following types of information:

- Name of person receiving the sample
- Laboratory sample number (if different from field number)
- Date of sample receipt
- Analyses to be performed (including desired analytical method)
- Information that may be useful to the laboratory (e.g., type and quantity of preservatives added, unusual conditions).

Laboratory Records

Once the sample has been received in the laboratory, the sample custodian and/or laboratory personnel should clearly document the processing steps that are applied to the sample. All sample preparation (e.g., extraction) and determinative steps should be identified in the laboratory records. Deviations from established methods or standard operating procedures (SOPs), such as the use of specific reagents (e.g., solvents, acids), temperatures, reaction times, and instrument settings, should be noted. The results of the analyses of all quality control samples should be identified for each batch of ground-water samples analyzed. The laboratory logbook should include the time, date, and name of the person who performed each processing step.

Analytical Procedures

The requirements of 40 CFR Part 258 include detection and assessment monitoring activities. Under detection monitoring, the constituents listed in 40 CFR Part 258, Appendix I are to be analyzed for. This list includes volatile organic compounds (VOCs) and selected inorganic constituents. No specific analytical methods are cited in the regulations, but there is a requirement (40 CFR §258.53(h)(5)) that any practical quantitation limit (PQL) used in subsequent statistical analysis "be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility." Suggested test methods are listed in Appendix II of Part 258 for informational purposes only. Method 8240 (gas chromatography with packed column; mass spectrometry) and Method 8260 (gas chromatography with capillary column; mass spectrometry) are typical methods used for all Appendix I VOCs. The inorganic analyses can be performed using inductively coupled plasma atomic emission spectroscopy (ICP) Method 6010. These methods, as well as other methods appropriate to these analyses, are presented in *Tests Methods for Evaluating Solid Waste, Physical/Chemical Methods*, SW-846 (USEPA, 1986), and are routinely performed by numerous analytical testing laboratories. These methods typically provide PQLs in the 1 to 50 µg/L range. The ground-water monitoring plan must specify the analytical method to be used.

Evaluation and documentation of analytical performance requires that quality control samples be collected and analyzed along with the ground-water monitoring samples. Chapter One of SW-846 (Quality Assurance) describes the types of quality control samples necessary, as well as the frequency at which they must be collected and analyzed. In general, these quality control samples may include trip blanks, equipment rinsate samples, field duplicates, method blanks, matrix spikes and duplicates, and laboratory control samples.

Other mechanisms, including sample holding times, surrogate constituents, and standard additions, are also used to control and document data quality. The specification of and adherence to sample holding times minimizes the sample degradation that occurs over time. Evaluating the recovery of surrogate constituents spiked into organic samples allows the analyst and data user to monitor the efficiency of sample extraction and analysis. The method of standard additions is used to eliminate the effects of matrix interferences in inorganic analyses.

Quality Assurance/Quality Control

One of the fundamental responsibilities of the owner or operator is to establish a continuing program to ensure the reliability and validity of field and analytical laboratory data gathered as part of the overall ground-water monitoring program. The owner or operator must explicitly describe the QA/QC program that will be used in the laboratory. Most owners or operators will use commercial laboratories to conduct analyses of ground-water samples. In these cases, the owner or operator is responsible for ensuring that the laboratory of choice is exercising an appropriate QA/QC program.

The owner or operator should provide for the use of standards, laboratory blanks, duplicates, and spiked samples for calibration and identification of potential matrix interferences, especially for metal determinants. Refer to Chapter One of SW-846 for guidance. The owner or operator should use adequate statistical procedures (e.g., QC charts) to monitor and document performance and to implement an effective program to resolve testing problems (e.g., instrument maintenance, operator training). Data from QC samples (e.g., blanks, spiked samples) should be used as a measure of performance or as an indicator of potential sources of cross-contamination, but should not be used by the laboratory to alter or correct analytical data. All laboratory QC data should be submitted with the ground-water monitoring sample results.

Field Quality Assurance/Quality Control

To verify the precision of field sampling procedures, field QC samples, such as trip blanks, equipment blanks, and duplicates, should be collected. Additional volumes of sample also should be collected for laboratory QC samples.

All field QC samples should be prepared exactly as regular investigation samples with regard to sample volume, containers, and preservation. The concentrations of any contaminants found in blank samples should not be used to correct the ground-water data. The contaminant concentrations in blanks should be documented, and if the concentrations are more than an order of magnitude greater than the field sample results, the owner/operator should resample the ground water. The owner/operator should prepare the QC samples as recommended in Chapter One of SW-846 and at the frequency recommended by Chapter One of SW-846 and should analyze them for all of the required monitoring parameters. Other QA/QC practices, such as sampling equipment calibration, equipment decontamination procedures, and chain-of-custody procedures, are discussed in other sections of this chapter and should be described in the owner/operator's QAPjP.

Validation

The analytical data report provided by the laboratory will present all data measured by the laboratory but will not adjust those data for field or laboratory quality control indicators. This means that just because data have been reported, they are not necessarily an accurate representation of the quality of the ground water. For example, acetone and methylene chloride are often used in laboratories as cleaning and extraction solvents and, consequently, are often laboratory contaminants, transmitted through the ambient air into samples. Method blanks are analyzed to evaluate the extent of laboratory contamination. Constituents found as contaminants in the method blanks are "flagged" in the sample data. The sample data are not, however, adjusted for the contaminant concentration.

Other kinds of samples are analyzed to assess other data quality indicators. Trip blanks are used to assess contamination by volatile organic constituents during sample shipment and storage. Matrix spike/matrix spike duplicate sample pairs are used to evaluate analytical bias and precision. Equipment rinsate samples are used to assess the efficacy of sampling equipment decontamination procedures. The data validation process uses the results from all of these QC samples to determine if the reported analytical data accurately describe the samples. All reported data must be evaluated -- a reported value of "non-detect" is a quantitative report just like a numerical value and must be validated.

The data validation process must also consider the presence and quality of other kinds of data used to ensure data quality (e.g., calibration frequency and descriptors, matrix specific detection limits). All of the criteria for data quality are described in the quality assurance project plan (QAPjP) or sampling and analysis plan (SAP). These documents may reference criteria from some other source, (e.g., the USEPA Contract Laboratory Program). The performance criteria must be correctly specified and must be used for data validation. It is a waste of time and money to evaluate data against standards other than those used to generate them. Several documents are available to assist the reviewer in validation of data by different criteria (i.e., Chapter One of *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,* USEPA CLP *Functional Guidelines for Evaluating Organics Analyses,* USEPA CLP *Functional Guidelines for Evaluating Pesticides/PCBs Analyses,* etc.).

In addition to specific data that describe data quality, the validator may consider other information that may have an impact on the end-use of the data, such as background concentrations of the constituent in the environment. In any event, the QAPjP or SAP also should describe the validation procedures that will be used. The result of this validation should be the classification of data as acceptable or unacceptable for the purposes of the project. In some cases, data may be further qualified, based either on insufficient data or marginal performance (i.e., qualitative uses only, estimated concentration, etc.).

Documentation

The ground-water monitoring program required by §258.50 through §258.55 relies on documentation to demonstrate compliance. The operating record of the MSWLF should include a complete description of the program as well as periodic implementation reports.

At a minimum, the following aspects of the ground-water monitoring program should be described or included in the operating record:

- The Sampling and Analysis plan that details sample parameters, sampling frequency, sample collection, preservation, and analytical methods to be used, shipping procedures, and chain-of-custody procedures;

- The Quality Assurance Project Plan (QAPjP) and Data Quality Objectives (DQOs);

- The locations of monitoring wells;

- The design, installation, development, and decommission of monitoring wells, piezometers, and other measurement, sampling, and analytical devices;

- Site hydrogeology;

- Statistical methods to be used to evaluate ground-water monitoring data and demonstrate compliance with the performance standard;

- Approved demonstration that monitoring requirements are suspended (if applicable);

- Boring logs;

- Piezometer and well construction logs for the ground-water monitoring system.

5.9 STATISTICAL ANALYSIS 40 CFR §258.53 (g)-(i)

5.9.1 Statement of Regulation

(g) The owner or operator must specify in the operating record one of the following statistical methods to be used in evaluating ground-water monitoring data for each hazardous constituent. The statistical test chosen shall be conducted separately for each hazardous constituent in each well.

(1) A parametric analysis of variance (ANOVA) followed by multiple comparisons procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.

(2) An analysis of variance (ANOVA) based on ranks followed by multiple comparisons procedures to identify statistically significant evidence of contamination. The method must include

estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.

(3) A tolerance or prediction interval procedure in which an interval for each constituent is established from the distribution of the background data, and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.

(4) A control chart approach that gives control limits for each constituent.

(5) Another statistical test method that meets the performance standards of §258.53(h). The owner or operator must place a justification for this alternative in the operating record and notify the State Director of the use of this alternative test. The justification must demonstrate that the alternative method meets the performance standards of §258.53(h).

(h) Any statistical method chosen under §258.53(g) shall comply with the following performance standards, as appropriate:

(1) The statistical method used to evaluate ground-water monitoring data shall be appropriate for the distribution of chemical parameters or hazardous constituents. If the distribution of the chemical parameters or hazardous constituents is shown by the owner or operator to be inappropriate for a normal theory test, then the data should be transformed or a distribution-free theory test should be used. If the distributions for the constituents differ, more than one statistical method may be needed.

(2) If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a ground-water protection standard, the test shall be done at a Type I error level of no less than 0.01 for each testing period. If a multiple comparisons procedure is used, the Type I experiment wise error rate for each testing period shall be no less than 0.05; however, the Type I error of no less than 0.01 for individual well comparisons must be maintained. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.

(3) If a control chart approach is used to evaluate ground-water monitoring data, the specific type of control chart and its associated parameter values shall be protective of human health and the environment. The parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(4) If a tolerance interval or a predictional interval is used to evaluate ground-water monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, shall be protective of human health and the environment. These parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(5) The statistical method shall account for data below the limit of detection with one or more statistical procedures that are protective of human health and the environment. Any practical quantitation limit (PQL) that is used in the statistical method shall be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility.

(6) If necessary, the statistical method shall include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

(i) The owner or operator must determine whether or not there is a statistically significant increase over background values for each parameter or constituent required in the particular ground-water monitoring program that applies to the MSWLF unit, as determined under §§258.54(a) or 258.55(a) of this part.

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the ground-water quality of each parameter or constituent at each monitoring well designated pursuant to §258.51(a)(2) to the background value of that constituent, according to the statistical procedures and performance standards specified under paragraphs (g) and (h) of this section.

(2) Within a reasonable period of time after completing sampling and analysis, the owner or operator must determine whether there has been a statistically significant increase over background at each monitoring well.

5.9.2 Applicability

The statistical analysis requirements are applicable to all existing units, new units, and lateral expansions of existing units for which ground-water monitoring is required. The use of statistical procedures to evaluate monitoring data shall be used for the duration of the monitoring program, including the post-closure care period.

The owner or operator must indicate in the operating record the statistical method that will be used in the analysis of ground-water monitoring results. The data objectives of the monitoring, in terms of the number of samples collected and the frequency of collection, must be consistent with the statistical method selected.

Several options for analysis of ground-water data are provided in the criteria. Other methods may be used if they can be shown to meet the performance standards. The approved methods include both parametric and nonparametric procedures, which differ primarily in constraints placed by the statistical distribution of the data. Control chart, tolerance interval, and prediction interval approaches also may be applied.

The owner or operator must conduct the statistical comparisons between upgradient and downgradient wells after completion of each sampling event and receipt of validated data. The statistical procedure must conform to the performance standard of a Type I error level of no less than 0.01 for inter-well comparisons. Control chart, tolerance interval, and prediction interval approaches must incorporate decision values that are protective of human health and the environment. Generally, this is meant to include a significance level of a least 0.05. Procedures to treat data below analytical method detection levels and seasonality effects must be part of the statistical analysis.

5.9.3 Technical Considerations

The MSWLF rule requires facilities to evaluate ground-water monitoring data using a statistical method provided in §258.53(g) that meets the performance standard of §258.53(h). Section 258.53(g) contains a provision allowing for the use of an alternative statistical method as long as the performance standards of §258.53(h) are met.

The requirements of §258.53(g) specify that one of five possible statistical methods be used for evaluating ground-water monitoring data. One method should be specified for each constituent. Although different methods may be selected for each constituent at new facilities, use of a method must be substantiated by demonstrating that the distribution of data obtained on that constituent is appropriate for that method (§258.53(h)). Selection of a specific method is described in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance"* (USEPA, 1989) and in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Addendum to Interim Final Guidance* (USEPA, 1992b). EPA also offers software, entitled User Documentation of the Ground-Water Information Tracking System (GRITS) with Statistical Analysis Capability, GRITSTAT Version 4.2. In addition to the statistical guidance provided by EPA, the following references may be useful for selecting other methods (Dixon and Massey, 1969; Gibbons, 1976; Aitchison and Brown, 1969; and Gilbert, 1987). The statistical methods that may be used in evaluating ground-water monitoring data include the following:

- Parametric analysis of variance (ANOVA) with multiple comparisons
- Rank-based (nonparametric) ANOVA with multiple comparisons
- Tolerance interval or prediction interval
- Control chart
- An alternative statistical method (e.g., CABF t-test or confidence intervals).

If an alternative method is used, then the State Director must be notified, and a justification for its use must be placed in the operating record.

The statistical analysis methods chosen must meet performance standards specified under §258.53(h), which include the following:

1) The method must be appropriate for the observed distribution of the data

2) Individual well comparisons to background ground-water quality or a ground-water protection standard shall be done at a Type I error level of no less than 0.01 or, if the multiple comparisons procedure is used, the experiment-wise error rate for each testing period shall be no less than 0.05

3) If a control chart is used, the type of chart and associated parameter values

shall be protective of human health and the environment

4) The level of confidence and percentage of the population contained in an interval shall be protective of human health and the environment

5) The method must account for data below the limit of detection (less than the PQL) in a manner that is protective of human health and the environment

6) The method must account for seasonal and spatial variability and temporal correlation of the data, if necessary.

These statistical analysis methods shall be used to determine whether a significant increase over background values has occurred. Monitoring data must be statistically analyzed after validated results from each sampling and analysis event are received.

The statistical performance standards provide a means to limit the possibility of making false conclusions from the monitoring data. The specified error level of 0.01 for individual well comparisons for probability of Type I error (indication of contamination when it is not present or false positive) essentially means that the analysis is predicting with 99-percent confidence that no significant increase in contaminant levels is evident when in fact no increase is present. Non-detect results must be treated in an appropriate manner or their influence on the statistical method may invalidate the statistical conclusion. Non-detect results are discussed in greater detail later in this section.

Multiple Well Comparisons

If more than two wells (background and downgradient combined) are screened in the same stratigraphic unit, then the appropriate statistical comparison method is a multiple well comparison using the ANOVA procedure. The parametric ANOVA procedure assumes that the data from each well group come from the same type (e.g., Normal) of distribution with possibly different mean concentrations. The ANOVA tests for a difference in means. If there are multiple background wells, one should consider the possibility of trying to pool these background data into one group. Such an increase in sample size often allows for more accurate statistical comparisons, primarily because better information is known about the background concentrations as a whole. Downgradient wells should not be pooled, as stated in the regulations. Ground-water monitoring data tend to follow a log normal distribution (USEPA, 1989), and usually need to be transformed prior to applying a parametric ANOVA procedure. By conducting a log transformation, ground-water monitoring data will generally be converted to a normal distribution. By applying a Shapiro-Wilk test, probability plots, or other normality tests on the residuals (errors) from the ANOVA procedure, the normality of the transformed data can be determined. In addition, data variance for each well in the comparison must be approximately equivalent; this condition can be checked using Levene's or Bartlett's test. These tests are provided in USEPA (1992b) and USEPA (1989).

If the transformed data do not conform to the normality assumption, a nonparametric ANOVA procedure may be used. The nonparametric statistical procedures do not depend as much on the mathematical properties of a specified distribution. The nonparametric equivalent to the parametric ANOVA is the Kruskal-Wallis test, which analyzes variability of the average ranks of the data instead of the measurements themselves.

If the data display seasonality (regular, periodic, and time-dependent increases or decreases in parameter values), a two-way ANOVA procedure should be used. If the seasonality can be corrected, a one-way ANOVA procedure may still be appropriate. Methods to treat seasonality are described in USEPA (1989).

ANOVA procedures attempt to determine whether different wells have significantly different average concentrations of constituents. If a difference is indicated, the ANOVA test is followed by a multiple comparisons procedure to investigate which specific wells are different among those tested. The overall experiment-wise significance level of the ANOVA must be kept to a minimum of 0.05, while the minimum significance level of each individual comparison must be set at 0.01. USEPA (1992b) provides alternative methods that can be used when the number of individual contrasts to be tested is very high.

Tolerance and Prediction Intervals

Two types of statistical intervals are often constructed from data: tolerance intervals and prediction intervals. A comprehensive discussion of these intervals is provided in USEPA 1992b. Though often confused, the interpretations and uses of these intervals are quite distinct. A tolerance interval is designed to contain a designated proportion of the population (e.g., 95 percent of all possible sample measurements). Because the interval is constructed from sample data, it also is a random interval. And because of sampling fluctuations, a tolerance interval can contain the specified proportion of the population only with a certain confidence level.

Tolerance intervals are very useful for ground-water data analysis because in many situations one wants to ensure that at most a small fraction of the compliance well sample measurements exceed a specific concentration level (chosen to be protective of human health and the environment).

Prediction intervals are constructed to contain the next sample value(s) from a population or distribution with a specified probability. That is, after sampling a background well for some time and measuring the concentration of an analyte, the data can be used to construct an interval that will contain the next analyte sample or samples (assuming the distribution has not changed). Therefore, a prediction interval will contain a future value or values with specified probability. Prediction intervals can also be constructed to contain the average of several future observations.

In summary, a tolerance interval contains a proportion of the population, and a prediction interval contains one or more future observations. Each has a probability statement or "confidence coefficient" associated with it. It should be noted that these intervals assume that the sample data used to construct the intervals are normally distributed.

Individual Well Comparisons

When only two wells (e.g., a single background and a single compliance point well) are being compared, owners or operators should not perform the parametric or nonparametric ANOVA. Instead, a parametric t-test, such as Cochran's Approximation to the Behrens-Fisher Students' t-test, or a nonparametric test should be performed. When a single compliance well group is being compared to background data and a nonparametric test is needed, the Wilcoxin Rank-Sum test should be performed. These tests are discussed in more detail in standard statistical references and in USEPA (1992b).

Intra-Well Comparisons

Intra-well comparisons, where data of one well are evaluated over time, are useful in evaluating trends in individual wells and for identifying seasonal effects in the data. The intra-well comparison methods do not compare background data to compliance data. Where some existing facilities may not have valid background data, however, intra-well comparisons may represent the only valid comparison available. In the absence of a true background well, several monitoring events may be required to determine trends and seasonal fluctuations in ground-water quality.

Control charts may be used for intra-well comparisons but are only appropriate for uncontaminated wells. If a well is intercepting a release, then it is already in an "out-of-control" state, which violates the principal assumption underlying control chart procedures. Time series analysis (i.e., plotting concentrations over time) is extremely useful for identifying trends in monitoring data. Such data may be adjusted for seasonal effects to aid in assessing the degree of change over time. Guidance for and limitations of intra-well comparison techniques are provided in USEPA (1989) and USEPA (1992b).

Treatment of Non-Detects

The treatment of data below the detection limit of the analytical method (non-detects) used depends on the number or percentage of non-detects and the statistical method employed. Guidance on how to treat non-detects is provided in USEPA (1992b).

5.10 DETECTION MONITORING PROGRAM 40 CFR §258.54

5.10.1 Statement of Regulation

(a) Detection monitoring is required at MSWLF units at all ground-water monitoring wells defined under §§258.51(a)(1) and (a)(2) of this part. At a minimum, a detection monitoring program must include the monitoring for the constituents listed in Appendix I of this part.

1) The Director of an approved State may delete any of the Appendix I monitoring parameters for a MSWLF unit if it can be shown that the removed constituents are not reasonably expected to be in or derived from the waste contained in the unit.

2) The Director of an approved State may establish an alternative list of inorganic indicator parameters for a MSWLF unit, in lieu of some or all of

the heavy metals (constituents 1-15 in Appendix I), if the alternative parameters provide a reliable indication of inorganic releases from the MSWLF unit to the ground water. In determining alternative parameters, the Director shall consider the following factors:

(i) The types, quantities, and concentrations of constituents in wastes managed at the MSWLF unit;

(ii) The mobility, stability, and persistence of waste constituents or their reaction products in the unsaturated zone beneath the MSWLF unit;

(iii) The detectability of indicator parameters, waste constituents, and reaction products in the ground water; and

(iv) The concentration or values and coefficients of variation of monitoring parameters or constituents in the background ground-water.

(b) The monitoring frequency for all constituents listed in Appendix I, or the alternative list approved in accordance with paragraph (a)(2), shall be at least semiannual during the active life of the facility (including closure) and the post-closure period. A minimum of four independent samples from each well (background and downgradient) must be collected and analyzed for the Appendix I constituents, or the alternative list approved in accordance with paragraph (a)(2), during the first semiannual sampling event. At least one sample from each well(background and downgradient) must be collected and analyzed during subsequent semiannual sampling events. The Director of an approved State may specify an appropriate alternative frequency for repeated sampling and analysis for Appendix I constituents, or the alternative list approved in accordance with paragraph (a)(2), during the active life (including closure) and the post-closure care period. The alternative frequency during the active life (including closure) shall be no less than annual. The alternative frequency shall be based on consideration of the following factors:

1) Lithology of the aquifer and unsaturated zone;

2) Hydraulic conductivity of the aquifer and unsaturated zone;

3) Ground-water flow rates;

4) Minimum distance between upgradient edge of the MSWLF unit and downgradient monitoring well screen (minimum distance of travel); and

5) Resource value of the aquifer.

(c) If the owner or operator determines, pursuant to §258.53(g) of this part, that there is a statistically significant increase over background for one or more of the constituents listed in Appendix I or the alternative list approved in accordance with paragraph (a)(2), at any monitoring well at the boundary specified under §258.51(a)(2), the owner or operator:

(1) Must, within 14 days of this finding, place a notice in the operating record indicating which constituents have shown statistically significant changes from

background levels, and notify the State Director that this notice was placed in the operating record; and

(2) Must establish an assessment monitoring program meeting the requirements of §258.55 of this part within 90 days, except as provided for in paragraph (3) below.

(3) The owner/operator may demonstrate that a source other than a MSWLF unit caused the contamination or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. A report documenting this demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State and be placed in the operating record. If a successful demonstration is made and documented, the owner or operator may continue detection monitoring as specified in this section. If after 90 days, a successful demonstration is not made, the owner or operator must initiate an assessment monitoring program as required in §258.55.

5.10.2 Applicability

Except for the small landfill exemption and the no migration demonstration, detection monitoring is required at existing MSWLF units, lateral expansions of units, and new MSWLF units. Monitoring must occur at least semiannually at both background wells and downgradient well locations. The Director of an approved State may specify an alternative sampling frequency. Monitoring parameters must include all Appendix I constituents unless an alternative list has been established by the Director of an approved State.

During the first semiannual monitoring event, the owner or operator must collect at least four independent ground-water samples from each well and analyze the samples for all constituents in the Appendix I or alternative list. Each subsequent semiannual event must include, at a minimum, the collection and analysis of one sample from all wells. The monitoring requirement continues throughout the active life of the landfill and the post-closure care period.

If an owner or operator determines that a statistically significant increase over background has occurred for one or more Appendix I constituents (or constituents on an alternative list), a notice must be placed in the facility operating record (see Table 5-2). The owner or operator must notify the State Director within 14 days of the finding. Within 90 days, the owner or operator must establish an assessment monitoring program conforming to the requirements of §258.55.

If evidence exists that a statistically significant increase is due to factors unrelated to the unit, the owner or operator may make a demonstration to this effect to the Director of an approved State or place a certified demonstration in the operating record. The potential reasons for an apparent statistical increase may include:

- A contaminant source other than the landfill unit
- A natural variation in ground-water quality
- An analytical error

- A statistical error
- A sampling error.

The demonstration that one of these reasons is responsible for the statistically significant increase over background must be certified by a qualified ground-water scientist or approved by the Director of an approved State. If a successful demonstration is made and documented, the owner or operator may continue detection monitoring.

If a successful demonstration is not made within 90 days, the owner or operator must initiate an assessment monitoring program. A flow chart for a detection monitoring program in a State whose program has not been approved by EPA is provided in Figure 5-5.

5.10.3 Technical Considerations

If there is a statistically significant increase over background during detection monitoring for one or more constituents listed in Appendix I of Part 258 (or an alternative list of parameters in an approved State), the owner or operator is required to begin assessment monitoring. The requirement to conduct assessment monitoring will not change, even if the Director of an approved State allows the monitoring of geochemical parameters in lieu of some or all of the metals listed in Appendix I. If an owner or operator suspects that a statistically significant increase in a geochemical parameter is caused by natural variation in ground-water quality or a source other than a MSWLF unit, a demonstration to this effect must be documented in a report to avoid proceeding to assessment monitoring.

Independent Sampling for Background

The ground-water monitoring requirements specify that four independent samples be collected from each well to establish background during the first semiannual monitoring event. This is because almost all statistical procedures are based on the assumption that samples are independent of each other. In other words, independent samples more accurately reflect the true range of natural variability in the ground water, and statistical analyses based on independent samples are more accurate. Replicate samples, whether field replicates or lab splits, are not statistically independent measurements.

It may be necessary to gather the independent samples over a range of time sufficient to account for seasonal differences. If seasonal differences are not taken into account, the chance for false positives increases (monitoring results indicate a release, when a release has not occurred). The sampling interval chosen must ensure that sampling is being done on different volumes of ground water. To determine the appropriate interval between sample collection events that will ensure independence, the owner or operator can determine the site's effective porosity, hydraulic conductivity, and hydraulic gradient and use this information to calculate ground-water velocity (USEPA, 1989). Knowing the velocity of the ground water should enable an owner/operator to establish an interval that ensures the four samples are being collected from four different volumes of water. For additional information on establishing sampling interval, see *Statistical Analysis of Groundwater Monitoring Data at RCRA*

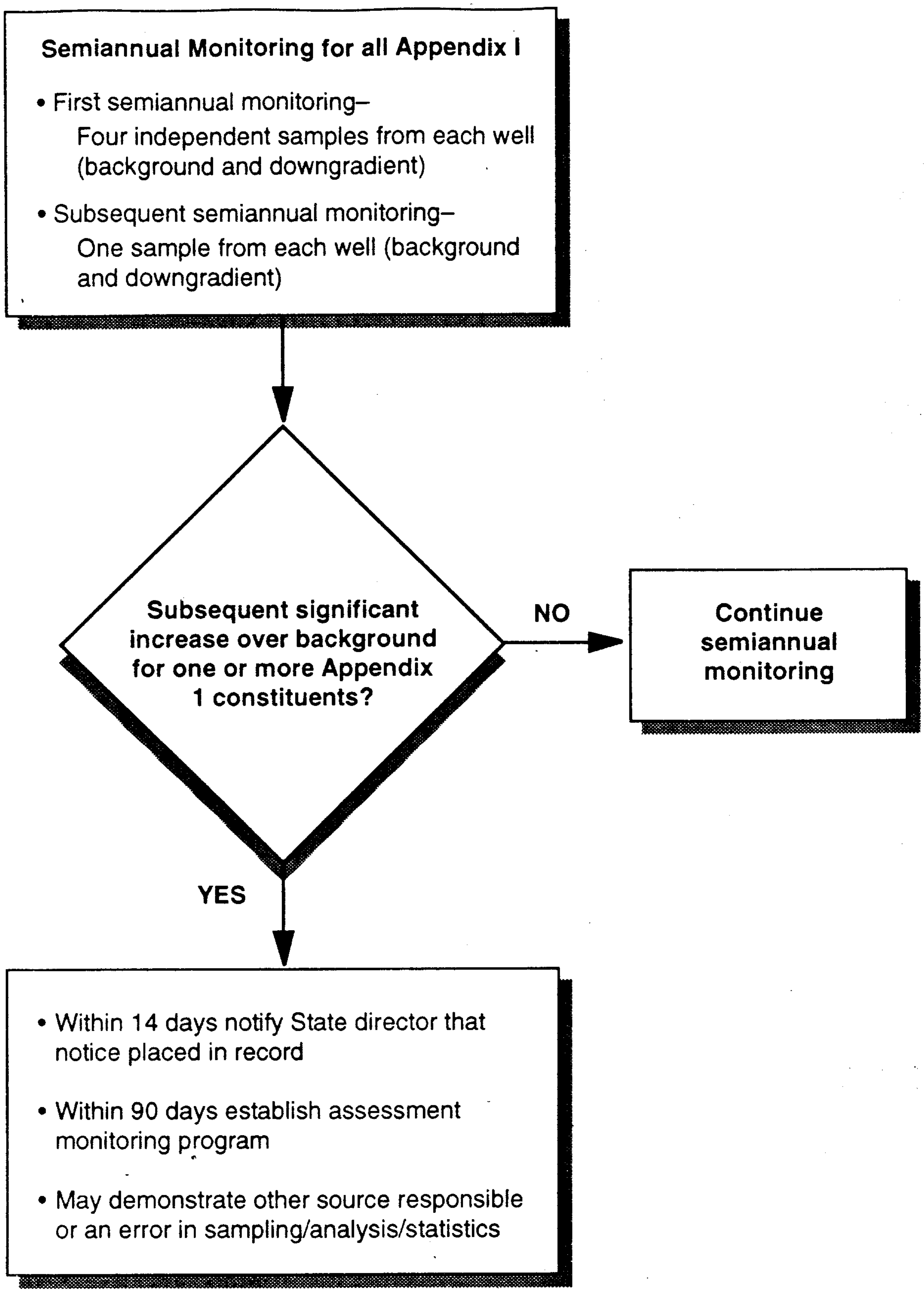


Figure 5-5. Detection Monitoring Program

Facilities - Interim Final Guidance, (USEPA, 1989).

Alternative List/Removal of Parameters

An alternative list of Appendix I constituents may be allowed by the Director of an approved State. The alternative list may use geochemical parameters, such as pH and specific conductance, in place of some or all of the metals (Parameters 1 through 15) in Appendix I. These alternative parameters must provide a reliable indication of inorganic releases from the MSWLF unit to ground water. The option of establishing an alternative list applies only to Parameters 1 through 15 of Appendix I. The list of ground-water monitoring parameters must include all of the volatile organic compounds (Appendix I, Parameters 16 through 62).

A potential problem in substituting geochemical parameters for metals on the alternative list is that many of the geochemical parameters are naturally occurring. However, these parameters have been used to indicate releases from MSWLF units. Using alternative geochemical parameters is reasonable in cases where natural background levels are not high enough to mask the detection of a release from a MSWLF unit. The decision to use alternative parameters also should consider natural spatial and temporal variability in the geochemical parameters.

The types, quantities, and concentrations of wastes managed at the MSWLF unit play an important role in determining whether removal of parameters from Appendix I is appropriate. If an owner or operator has definite knowledge of the nature of wastes accepted at the facility, then removal of constituents from Appendix I may be acceptable. Usually, a waste would have to be homogeneous to allow for this kind of determination. The owner or operator may submit a demonstration that documents the presence or absence of certain constituents in the waste. The owner or operator also would have to demonstrate that constituents proposed for deletion from Appendix I are not degradation or reaction products of constituents potentially present in the waste.

Alternative Frequency

In approved States, 40 CFR §258.54(b) allows the Director to specify an alternative frequency for ground-water monitoring. The alternative frequency is applicable during the active life, including the closure and the post-closure periods. The alternative frequency can be no less than annual.

The need to vary monitoring frequency must be evaluated on a site-specific basis. For example, for MSWLF units located in areas with low ground-water flow rates, it may be acceptable to monitor ground water less frequently. The sampling frequency chosen must be sufficient to protect human health and the environment. Depending on the ground-water flow rate and the resource value of the aquifer, less frequent monitoring may be allowable or more frequent monitoring may be necessary. An approved State may specify an alternative frequency for repeated sampling and analysis of Appendix I constituents based on the following factors:

1) Lithology of the aquifer and the unsaturated zone

2) Hydraulic conductivity of the aquifer and the unsaturated zone

3) Ground-water flow rates

4) Minimum distance between the upgradient edge of the MSWLF unit and the downgradient well screen

5) The resource value of the aquifer.

Approved States also can set alternative frequencies for monitoring during the post-closure care period based on the same factors.

Notification

The notification requirement under 40 CFR §258.54(c) requires an owner or operator to 1) place a notice in the operating record that indicates which constituents have shown statistically significant increases and 2) notify the State Director that the notice was placed in the operating record. The constituents can be from either Appendix I or from an alternative list.

Demonstrations of Other Reasons For Statistical Increase

An owner or operator is allowed 90 days to demonstrate that the statistically significant increase of a contaminant/constituent was caused by statistical, sampling, or analytical errors or by a source other than the landfill unit. The demonstration allowed in §258.54(c)(3) may include:

1) A demonstration that the increase resulted from another contaminant source

2) A comprehensive audit of sampling, laboratory, and data evaluation procedures

3) Resampling and analysis to verify the presence and concentration of the constituents for which the increase was reported.

A demonstration that the increase in constituent concentration is the result of a source other than the MSWLF unit should document that:

- An alternative source exists.
- Hydraulic connection exists between the alternative source and the well with the significant increase.
- Constituent(s) (or precursor constituents) are present at the alternative source or along the flow path from the alternative source prior to possible release from the MSWLF unit.
- The relative concentration and distribution of constituents in the zone of contamination are more strongly linked to the alternative source than to the MSWLF unit when the fate and transport characteristics of the constituents are considered.
- The concentration observed in ground water could not have resulted from the MSWLF unit given the waste constituents and concentrations in the MSWLF unit leachate and wastes, and site hydrogeologic conditions.
- The data supporting conclusions regarding the alternative source are historically consistent with hydrogeologic

conditions and findings of the monitoring program.

The demonstration must be documented, certified by a qualified ground-water scientist, and placed in the operating record of the facility.

Demonstrations of Other Sources of Error

A successful demonstration that the statistically significant change is the result of an error in sampling, analysis, or data evaluation may include the following:

- Clear indication of a transcription or calculation error
- Clear indication of a systematic error in analysis or data reduction
- Resampling, analysis, and evaluation of results
- Corrective measures to prevent the recurrence of the error and incorporation of these measures into the ground-water monitoring program.

If resampling is necessary, the sample(s) taken must be independent of the previous sample. More than one sample may be required to substantiate the contention that the original sample was not representative of the ground-water quality in the affected well(s).

5.11 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(a)-(f)

5.11.1 Statement of Regulation

(a) Assessment monitoring is required whenever a statistically significant increase over background has been detected for one or more of the constituents listed in Appendix I or in the alternate list approved in accordance with § 258.54(a)(2).

(b) Within 90 days of triggering an assessment monitoring program, and annually thereafter, the owner or operator must sample and analyze the ground water for all constituents identified in Appendix II of this part. A minimum of one sample from each downgradient well must be collected and analyzed during each sampling event. For any new constituent detected in the downgradient wells as a result of the complete Appendix II analysis, a minimum of four independent samples from each well (background and downgradient) must be collected and analyzed to establish background for the new constituents. The Director of an approved State may specify an appropriate subset of wells to be sampled and analyzed for Appendix II constituents during assessment monitoring. The Director of an approved State may delete any of the Appendix II monitoring parameters for a MSWLF unit if it can be shown that the removed constituents are not reasonably expected to be contained in or derived from the waste contained in the unit.

(c) The Director of an approved State may specify an appropriate alternate frequency for repeated sampling and analysis for the full set of Appendix II constituents required by §258.55(b) of this part, during the active life (including closure) and post-closure care of the unit considering the following factors:

(1) Lithology of the aquifer and unsaturated zone;

(2) Hydraulic conductivity of the aquifer and unsaturated zone;

(3) Ground-water flow rates;

(4) Minimum distance between upgradient edge of the MSWLF unit and downgradient monitoring well screen (minimum distance of travel);

(5) Resource value of the aquifer; and

(6) Nature (fate and transport) of any constituents detected in response to this section.

(d) After obtaining the results from the initial or subsequent sampling events required in paragraph (b) of this section, the owner or operator must:

(1) Within 14 days, place a notice in the operating record identifying the Appendix II constituents that have been detected and notify the State Director that this notice has been placed in the operating record;

(2) Within 90 days, and on at least a semiannual basis thereafter, resample all wells specified by § 258.51(a), conduct analyses for all constituents in Appendix I to this Part or in the alternative list approved in accordance with §258.54(a)(2), and for those constituents in Appendix II that are detected in response to paragraph (b) of this section, and record their concentrations in the facility operating record. At least one sample from each well (background and downgradient) must be collected and analyzed during these sampling events. The Director of an approved State may specify an alternative monitoring frequency during the active life (including closure) and the post closure period for the constituents referred to in this paragraph. The alternative frequency for Appendix I constituents or the alternate list approved in accordance with §258.54(a)(2) during the active life (including closure) shall be no less than annual. The alternative frequency shall be based on consideration of the factors specified in paragraph (c) of this section;

(3) Establish background concentrations for any constituents detected pursuant to paragraphs (b) or (d)(2) of this section; and

(4) Establish ground-water protection standards for all constituents detected pursuant to paragraph (b) or (d)(2) of this section. The ground-water protection standards shall be established in accordance with paragraphs (h) or (i) of this section.

(e) If the concentrations of all Appendix II constituents are shown to be at or below background values, using the statistical procedures in §258.53(g), for two consecutive sampling events, the owner or operator must notify the State

Director of this finding and may return to detection monitoring.

(f) If the concentrations of any Appendix II constituents are above background values, but all concentrations are below the ground-water protection standard established under paragraphs (h) or (i) of this section, using the statistical procedures in §258.53(g), the owner or operator must continue assessment monitoring in accordance with this section.

5.11.2 Applicability

Assessment monitoring is required at all existing units, lateral expansions, and new facilities whenever any of the constituents listed in Appendix I are detected at a concentration that is a statistically significant increase over background values. Figure 5-6 presents a flow chart pertaining to applicability requirements.

Within 90 days of beginning assessment monitoring, the owner or operator must resample all downgradient wells and analyze the samples for all Appendix II constituents. If any new constituents are identified in this process, four independent samples must be collected from all upgradient and downgradient wells and analyzed for those new constituents to establish background concentrations. The complete list of Appendix II constituents must be monitored in each well annually for the duration of the assessment monitoring program. In an approved State, the Director may reduce the number of Appendix II constituents to be analyzed if it can be reasonably shown that those constituents are not present in or derived from the wastes. The Director of an approved State may specify an appropriate subset of wells to be included in the assessment monitoring program. The Director of an approved State also may specify an alternative frequency for repeated sampling and analysis of Appendix II constituents. This frequency may be decreased or increased based upon consideration of the factors in §258.55(c)(1)-(6). These options for assessment monitoring programs are available only with the approval of the Director of an approved State.

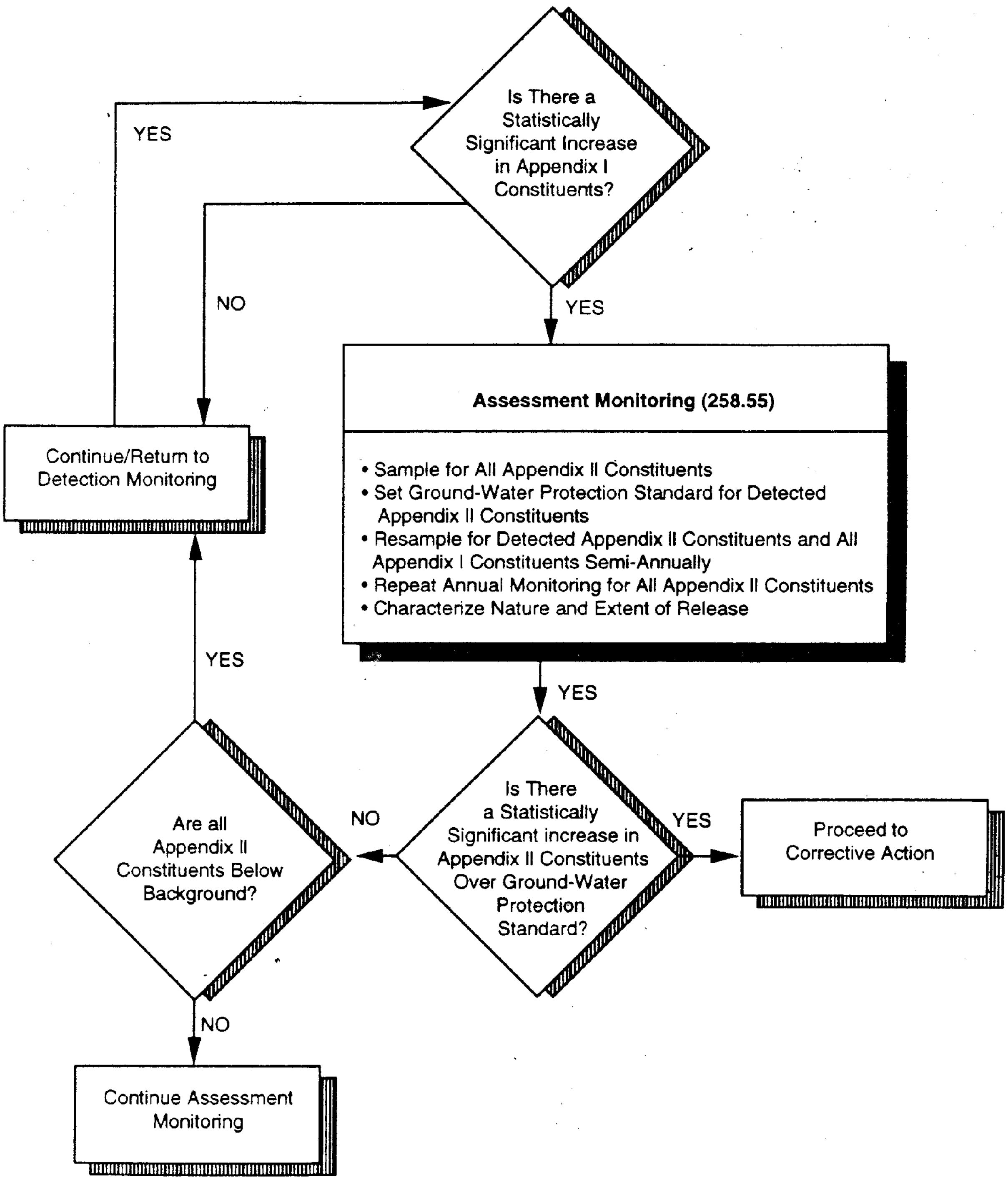
Within 14 days of receiving the results of the initial sampling for Appendix II constituents under assessment monitoring, the owner or operator must place the results in the operating record and notify the State Director that this notice has been placed in the operating record.

Within 90 days of receiving these initial results, the owner or operator must resample all wells for all Appendix I and detected Appendix II constituents. This combined list of constituents must be sampled at least semiannually thereafter, and the list must be updated annually to include any newly detected Appendix II constituents.

Within the 90-day period, the owner or operator must establish background values and ground-water protection standards (GWPSs) for all Appendix II constituents detected. The requirements for determining GWPSs are provided in §258.55(h). If the concentrations of all Appendix II constituents are at or below the background values after two independent, consecutive sampling events, the owner or operator may return to detection monitoring after notification has been made to the State Director. If, after these two

Figure 5-6

ASSESSMENT MONITORING



sampling events, any detected Appendix II constituent is statistically above background but below the GWPSs, the assessment monitoring program must be continued.

5.11.3 Technical Considerations

The purpose of assessment monitoring is to evaluate the nature and extent of contamination. The assessment monitoring program is phased. The first phase assesses the presence of additional assessment monitoring constituents (Appendix II or a revised list designated by an approved State) in all downgradient wells or in a subset of ground-water monitoring wells specified by the Director of an approved State. If concentrations of all Appendix II constituents are at or below background values using the statistical procedures in §258.53(g) for two consecutive sampling periods, then the owner or operator can return to detection monitoring.

Following notification of a statistically significant increase of any Appendix I constituent above background, the owner or operator has 90 days to develop and implement the assessment monitoring program. Implementation of the program involves sampling downgradient monitoring wells for ground water passing the relevant point of compliance for the unit (i.e., the waste management unit boundary or alternative boundary specified by the Director of an approved State). Downgradient wells are identified in §258.51(a)(2). Initiation of assessment monitoring does not stop the detection monitoring program. Section 258.55(d)(2) specifies that analyses must continue for all Appendix I constituents on at least a semiannual basis. Within the 90-day period, the owner or operator must collect at least one sample from each downgradient well and analyze the samples for the Appendix II parameters. If a downgradient well has detectable quantities of a new Appendix II constituent, four independent samples must be collected from all background and downgradient wells to establish background for the new constituent(s). The date, well locations, parameters detected, and their concentrations must be documented in the operating record of the facility, and the State Director must be notified within 14 days of the initial detection of Appendix II parameters. On a semiannual basis thereafter, both background and downgradient wells must be sampled for all Appendix II constituents.

Alternative List

In an approved State, the Director may delete Appendix II parameters that the owner or operator can demonstrate would not be anticipated at the facility. A demonstration would be based on a characterization of the wastes contained in the unit and an assessment of the leachate constituents. Additional information on the alternative list can be found in Section 5.10.3.

Alternative Frequency

The Director of an approved State may specify an alternate sampling frequency for the entire Appendix II list for both the active and post-closure periods of the facility. The decision to change the monitoring frequency must consider:

1) Lithology of the aquifer and unsaturated zone;

2) Hydraulic conductivity of the aquifer and unsaturated zone;

3) Ground-water flow rates;

4) Minimum distance of travel (between the MSWLF unit edge to downgradient monitoring wells); and

5) Nature (fate and transport) of the detected constituents.

The Director of an approved State also may allow an alternate frequency, other than semiannual, for the monitoring of Appendix I and detected Appendix II constituents.

The monitoring frequency must be sufficient to allow detection of ground-water contamination. If contamination is detected early, the volume of ground water contaminated will be smaller and the required remedial response will be less burdensome. Additional information on the alternate frequency can be found in Section 5.10.3.

In an approved State, the Director may specify a subset of wells that can be monitored for Appendix II constituents to confirm a release and track the plume of contamination during assessment monitoring. The owner or operator should work closely with the State in developing a monitoring plan that targets the specific areas of concern, if possible. This may represent a substantial cost savings, especially at large facilities for which only a very small percentage of wells showed exceedances above background. The use of a subset of wells likely will be feasible only in cases where the direction and rate of flow are relatively constant.

5.12 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(g)

5.12.1 Statement of Regulation

(g) If one or more Appendix II constituents are detected at statistically significant levels above the ground-water protection standard established under paragraphs (h) or (i) of this section in any sampling event, the owner or operator must, within 14 days of this finding, place a notice in the operating record identifying the Appendix II constituents that have exceeded the ground-water protection standard and, notify the State Director and all appropriate local government officials that the notice has been placed in the operating record. The owner or operator also:

(1) (i) Must characterize the nature and extent of the release by installing additional monitoring wells as necessary;

(ii) Must install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well in accordance with §258.55(d)(2);

(iii) Must notify all persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site if indicated by sampling of wells in accordance with §258.55(g)(i); and

(iv) Must initiate an assessment of corrective measures as required by §255.56 of this part within 90 days; or

(2) May demonstrate that a source other than a MSWLF unit caused the contamination, or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. A report documenting this demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State and placed in the operating record. If a successful demonstration is made the owner or operator must continue monitoring in accordance with the assessment monitoring program pursuant to §258.55, and may return to detection monitoring if the Appendix II constituents are below background as specified in §258.55(e). Until a successful demonstration is made, the owner or operator must comply with §258.55(g) including initiating an assessment of corrective measures.

5.12.2 Applicability

This requirement applies to facilities in assessment monitoring and is applicable during the active life, closure, and post-closure care periods.

5.12.3 Technical Considerations

If an Appendix II constituent(s) exceeds a GWPS in any sampling event, the owner or operator must notify the State Director within 14 days and place a notice of these findings in the operating record of the MSWLF facility. In addition, the owner or operator must:

1) Characterize the lateral and vertical extent of the release or plume by installing and sampling an appropriate number of additional monitoring wells

2) Install at least one additional downgradient well at the facility property boundary in the direction of migration of the contaminant plume and sample that well for all Appendix II compounds initially and thereafter, in conformance with the assessment monitoring program

3) Notify all property owners whose land overlies the suspected plume, if the sampling of any property boundary well(s) indicates that contaminants have migrated offsite

4) Initiate an assessment of corrective measures, as required by §258.56, within 90 days.

In assessment monitoring, the owner or operator may demonstrate that a source other than the MSWLF unit caused the contamination or that the statistically significant increase was the result of an error in sampling, analysis, statistical evaluation, or natural variation in ground-water quality. The demonstration must be certified by a qualified ground-water scientist or approved by the Director of an approved State. Until a successful demonstration is made, the owner or operator must comply with §258.55(g) and initiate assessment of corrective measures. If the demonstration is successful, the owner or operator must return to assessment monitoring and may return to the detection program provided that all Appendix II constituents are at or below background for two consecutive sampling periods.

Release Investigation

If the GWPS is exceeded, a series of actions must be taken. These actions are described in the next several paragraphs. The owner or operator must investigate the extent of the release by installing additional monitoring wells and obtaining additional ground-water samples. The investigation should identify plume geometry, both laterally and vertically. Prior to such field activities, records of site operation and maintenance activities should be reviewed to identify possible release locations within the landfill and whether such releases are expected to be transient (e.g., one time release due to repaired liner) or long-term. Due to the presence of dissolved ionic constituents, such as iron, magnesium, calcium, sodium, potassium, chloride, sulfate, and carbonate, typically associated with MSWLF unit leachates, geophysical techniques, including resistivity and terrain conductivity, may be useful in defining the plume. Characterizing the nature of the release should include a description of the rate and direction of contaminant migration and the chemical and physical characteristics of the contaminants.

Property Boundary Monitoring Well

At least one monitoring well must be installed at the facility boundary in the direction of contaminant migration. Additional wells may be required to delineate the plume. Monitoring wells at the facility boundary should be screened to monitor all stratigraphic units that could be preferential pathways for contaminant migration in the uppermost aquifer. In some cases, this may require installation of nested wells or individual wells screened at several discrete intervals. The well installed at the facility boundary must be sampled semiannually or at an alternative frequency determined by the Director of an approved State. The initial sample must be analyzed for all Appendix II constituents.

Notification of Adjoining Residents and Property Owners

If ground-water monitoring indicates that contamination has migrated offsite, the owner or operator must notify property owners or residents whose land surface overlies any part of the contaminant release. Although the requirement does not describe the contents of the notice, it is expected that the notice could include the following items:

- Date of detected release
- Chemical composition of release
- Reference to the constituent(s), reported concentration(s), and the GWPS
- Representatives of the MSWLF facility with whom to discuss the finding, including their telephone numbers
- Plans and schedules for future activities
- Interim recommendations or remedies to protect human health and the environment.

Demonstrations of Other Sources of Error

The owner or operator may demonstrate that the source of contamination was not the MSWLF unit. This demonstration is discussed in Section 5.10.3.

Return to Detection Monitoring

A facility conducting assessment monitoring may return to detection monitoring if the concentrations of all Appendix II constituents are at or below background levels for two consecutive sampling periods using the statistical procedures in §258.53(g). The requirement that background concentrations must be maintained for two consecutive sampling events will reduce the possibility that the owner or operator will fail to detect contamination or an increase in a concentration of a hazardous constituent when one actually exists. The Director of an approved State can establish an alternative time period (§258.54(b).

5.13 ASSESSMENT MONITORING PROGRAM 40 CFR §258.55(h)-(j)

5.13.1 Statement of Regulation

(h) The owner or operator must establish a ground-water protection standard for each Appendix II constituent detected in the ground water. The ground-water protection standard shall be:

(1) For constituents for which a maximum contaminant level (MCL) has been promulgated under Section 1412 of the Safe Drinking Water Act (codified) under 40 CFR Part 141, the MCL for that constituent;

(2) For constituents for which MCLs have not been promulgated, the background concentration for the constituent established from wells in accordance with §258.51(a)(1); or

(3) For constituents for which the background level is higher than the MCL identified under subparagraph (1) above or health based levels identified under §258.55(i)(1), the background concentration.

(i) The Director of an approved State may establish an alternative ground-water protection standard for constituents for which MCLs have not been established. These ground-water protection standards shall be appropriate health based levels that satisfy the following criteria:

(1) The level is derived in a manner consistent with Agency guidelines for assessing the health risks of environmental pollutants (51 FR 33992, 34006, 34014, 34028);

(2) The level is based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR Part 792) or equivalent;

(3) For carcinogens, the level represents a concentration associated with an excess lifetime cancer risk level (due to continuous lifetime exposure) with the 1 x 10^{-4} to 1 x 10^{-6} range; and

(4) For systemic toxicants, the level represents a concentration to which the human population (including sensitive subgroups) could be exposed to on a daily basis that is likely to be without appreciable risk of deleterious effects during a lifetime. For purposes of this subpart, systemic toxicants include toxic chemicals that cause effects other than cancer or mutation.

(j) In establishing ground-water protection standards under paragraph (i), the Director of an approved State may consider the following:

(1) Multiple contaminants in the ground water;

(2) Exposure threats to sensitive environmental receptors; and

(3) Other site-specific exposure or potential exposure to ground water.

5.13.2 Applicability

The criteria for establishing GWPSs are applicable to all facilities conducting assessment monitoring where any Appendix II constituents have been detected. The owner or operator must establish a GWPS for each Appendix II constituent detected.

If the constituent has a promulgated maximum contaminant level (MCL), then the GWPS is the MCL. If no MCL has been published for a given Appendix II constituent, the background concentration of the constituent becomes the GWPS. In cases where the background concentration is higher than a promulgated MCL, the GWPS is set at the background level.

In approved States, the Director may establish an alternative GWPS for constituents for which MCLs have not been established. Any alternative GWPS must be health-based levels that satisfy the criteria in §258.55(i). The Director may also consider any of the criteria identified in §258.55(j). In cases where the background concentration is higher than the health-based levels, the GWPS is set at the background level.

5.13.3 Technical Considerations

For each Appendix II constituent detected, a GWPS must be established. The GWPS is to be set at either the MCL or background. Where the background concentration is higher than the MCL, then the GWPS is established at background.

Directors of approved States have the option of establishing an alternative GWPS for constituents without MCLs. This alternative GWPS must be an appropriate health-based level, based on specific criteria. These levels must:

- Be consistent with EPA health risk assessment guidelines
- Be based on scientifically valid studies
- Be within a risk range of $1x10^{-4}$ to $1x10^{-6}$ for carcinogens
- For systemic toxicants (causing effects other than cancer or mutations), be a concentration to which the human population could be exposed on a daily basis without appreciable risk of deleterious effects during a lifetime.

The health-based GWPS may be established considering the presence of more than one constituent, exposure to sensitive environmental receptors, and other site-specific exposure to ground water. Risk assessments to establish the GWPS must consider cumulative effects of multiple pathways to receptors and cumulative effects on exposure risk of multiple contaminants. Guidance and procedures for establishing a health-based risk assessment may be found in *Guidance on Remedial Actions for*

Contaminated Groundwater at Superfund Sites, (USEPA, 1988).

5.14 ASSESSMENT OF CORRECTIVE MEASURES 40 CFR §258.56

5.14.1 Statement of Regulation

(a) Within 90 days of finding that any of the constituents listed in Appendix II have been detected at a statistically significant level exceeding the ground-water protection standards defined under §258.55(h) and (i) of this part, the owner or operator must initiate an assessment of corrective measures. Such an assessment must be completed within a reasonable period of time.

(b) The owner or operator must continue to monitor in accordance with the assessment monitoring program as specified in §258.55.

(c) The assessment shall include an analysis of the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under §258.57, addressing at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy;

(3) The costs of remedy implementation; and

(4) The institutional requirements such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

(d) The owner or operator must discuss the results of the corrective measures assessment, prior to the selection of remedy, in a public meeting with interested and affected parties.

5.14.2 Applicability

An assessment of corrective measures must be conducted whenever any Appendix II constituents are detected at statistically significant levels exceeding the GWPS. The assessment of corrective measures must be initiated within 90 days of the finding. During the initiation of an assessment of corrective measures, assessment monitoring must be continued. The assessment of corrective measures must consider performance (including potential impacts), time, and cost aspects of the remedies. If implementation requires additional State or local permits, such requirements should be identified. Finally, the results of the corrective measures assessment must be discussed in a public meeting with interested and affected parties.

5.14.3 Technical Considerations

An assessment of corrective measures is site-specific and will vary significantly depending on the design and age of the facility, the completeness of the facility's historical records, the nature and concentration of the contaminants found in the ground water, the complexity of the site hydrogeology, and the facility's proximity to sensitive receptors. Corrective measures are generally approached from two directions: 1) identify and remediate the source of contamination and 2) identify and remediate the known contamination. Because each case will be site-specific, the owner or operator should be prepared to document that, to the best of his or her technical and financial abilities, a diligent effort has been made to complete the assessment in the shortest time practicable.

The factors listed in §258.56(c)(1) must be considered in assessing corrective measures. These general factors are discussed below in terms of source evaluation, plume delineation, ground-water assessment, and corrective measures assessment.

Source Evaluation

As part of the assessment of corrective measures, the owner or operator will need to identify the nature of the source of the release. The first step in this identification is a review of all available site information regarding facility design, wastes received, and onsite management practices. For newer facilities, this may be a relatively simple task. However, at some older facilities, detailed records of the facility's history may not be as well documented, making source definition more difficult. Design, climatological, and waste-type information should be used to evaluate the duration of the release, potential seasonal effects due to precipitation (increased infiltration and leachate generation), and possible constituent concentrations. If source evaluation is able to identify a repairable engineering condition that likely contributed to the cause of contamination (e.g., unlined leachate storage ponds, failed cover system, leaky leachate transport pipes, past conditions of contaminated storm overflow), such information should be considered as part of the assessment of corrective measures.

Existing site geology and hydrogeology information, ground-water monitoring results, and topographic and cultural information must be documented clearly and accurately. This information may include soil boring logs, test pit and monitoring well logs, geophysical data, water level elevation data, and other information collected during facility design or operation. The information should be expressed in a manner that will aid interpretation of data. Such data may include isopach maps of the thickness of the upper aquifer and important strata, isoconcentration maps of contaminants, flow nets, cross-sections, and contour maps. Additional guidance on data interpretation that may be useful in a source evaluation is presented in *RCRA Facility Investigation Guidance: Volume I - Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations*, (USEPA 1989a), *RCRA Facility Investigation Guidance: Volume IV - Case Study Examples*, (USEPA 1989d), and *Practical Guide For Assessing and Remediating Contaminated Sites* (USEPA 1989e).

Plume Delineation

To effectively assess corrective measures, the lateral and vertical extent of contamination must be known. When it is determined that a GWPS is exceeded during the assessment monitoring program, it may be necessary to install additional wells to characterize the contaminant plume(s). At least one additional well must be added at the property boundary in the direction of contaminant migration to allow timely notification to potentially affected parties if contamination migrates offsite.

The following circumstances may require additional monitoring wells:

- Facilities that have not determined the horizontal and vertical extent of the contaminant plume
- Locations where the subsurface is heterogeneous or where ground-water flow patterns are difficult to establish
- Mounding associated with MSWLF units.

Because the requirements for additional monitoring are site-specific, the regulation does not specifically establish cases where additional wells are necessary or establish the number of additional wells that must be installed.

During the plume delineation process, the owner or operator is not relieved from continuing the assessment monitoring program.

The rate of plume migration and the change in contaminant concentrations with time must be monitored to allow prediction of the extent and timing of impact to sensitive receptors. The receptors may include users of both ground-water and surface water bodies where contaminated ground water may be discharged. In some cases, transfer of volatile compounds from ground water to the soil and to the air may provide an additional migration pathway. Information regarding the aquifer characteristics (e.g., hydraulic conductivity, storage coefficients, and effective porosity) should be developed for modeling contaminant transport if sufficient data are not available. Anisotropy and heterogeneity of the aquifer must be evaluated, as well as magnitude and duration of source inputs, to help explain present and predicted plume configuration.

Currently, most treatment options for ground-water contamination at MSWLF units involve pump and treat or in-situ biological technologies (bio-remediation). The cost and duration of treatment depends on the size of the plume, the pumping characteristics of the aquifer, and the chemical transport phenomena. Source control and ground-water flow control measures to reduce the rate of contaminant migration should be included in the costs of any remedial activity undertaken. Ground-water modeling of the plume may be initiated to establish the following:

- The locations and pumping rates of withdrawal and/or injection wells
- Predictions of contaminant concentrations at exposure points
- Locations of additional monitoring wells
- The effect that source control options may have on ground-water remediation
- The effects of advection and dispersion, retardation, adsorption, and other attenuation processes on the plume dimensions and contaminant concentrations.

Any modeling effort must consider that simulations of remedial response measures and contaminant transport are based on many necessary simplifying assumptions, which affect the accuracy of the model. These assumptions include boundary conditions, the degree and spatial variability of anisotropy, dispersivity, effective porosity, stratigraphy, and the algorithms used to solve contaminant transport equations. Model selection should be appropriate for the amount of data available, and the technical uncertainty of the model results must be documented by a sensitivity analysis on the input parameters. A sensitivity analysis is generally done after model calibration by varying one input parameter at a time over a realistic range and then evaluating changes in model output. For additional information on modeling, refer to the Further Information Section of Chapter 5.0 and the *RCRA Facility Investigation Guidance: Volume II - Soil, Groundwater and Subsurface Gas Releases* (USEPA, 1989b).

Ground-Water Assessment

To assess the potential effectiveness of corrective measures for ground-water contamination, the following information is needed:

- Plume definition (includes the types, concentration, and spatial distribution of the contaminants)
- The amenability of the contaminants to specific treatment and potential for contaminants to interfere with treatability
- Fate of the contaminants (whether chemical transformations have, are, or may be occurring, and the degree to which the species are sorbed to the geologic matrix)
- Stratigraphy and hydraulic properties of the aquifer
- Treatment concentration goals and objectives.

The owner or operator should consider whether immediate measures to limit further plume migration (e.g., containment options) or measures to minimize further introduction of contaminants to ground water are necessary.

The process by which a remedial action is undertaken will generally include the following activities:

- Hydrogeologic investigation, which may include additional well installations, detailed vertical and lateral sampling to characterize the plume, and core sampling to determine the degree of sorption of constituents on the geologic matrix
- Risk assessment, to determine the impact on sensitive receptors, which may include identification of the need to develop treatment goals other than GWPSs
- Literature and technical review of treatment technologies considered for further study or implementation
- Evaluation of costs of different treatment options
- Estimation of the time required for completion of remediation under the different treatment options

- Bench-scale treatability studies conducted to assess potential effectiveness of options

- Selection of technology(ies) and proposal preparation for regulatory and public review and comment

- Full-scale pilot study for verification of treatability and optimization of the selected technology

- Initiation of full-scale treatment technology with adjustments, as necessary

- Continuation of remedial action until treatment goals are achieved.

Corrective Measures Assessment

To compare different treatment options, substantial amounts of technical information must be assembled and assessed. The objective of this information-gathering task is to identify the following items for each treatment technology:

- The expected performance of individual approaches

- The time frame when individual approaches can realistically be implemented

- The technical feasibility of the remediation, including new and innovative technologies, performance, reliability and ease of implementation, safety and cross media impacts

- The anticipated time frame when remediation should be complete

- The anticipated cost of the remediation, including capital expenditures, design, ongoing engineering, and monitoring of results

- Technical and financial capability of the owner or operator to successfully complete the remediation

- Disposal requirements for treatment residuals

- Other regulatory or institutional requirements, including State and local permits, prohibitions, or environmental restrictions that may affect the implementation of the proposed remedial activity.

The performance objectives of the corrective measures should be considered in terms of source reduction, cleanup goals, and cleanup time frame. Source reduction would include measures to reduce or stop further releases and may include the repair of existing facility components (liner systems, leachate storage pond liners, piping systems, cover systems), upgrading of components (liners and cover systems), or premature closure in extreme cases. The technology proposed as a cleanup measure should be the best available technology, given the practicable capability of the owner or operator.

The technologies identified should be reliable, based on their previous performance; however, new innovative technologies are not discouraged if they can be shown, with a reasonable degree of confidence, to be reliable.

Because most treatment processes, including biorestoration, potentially produce byproducts or release contaminants to different media (e.g., air stripping of volatile compounds), the impacts of such potential releases must be evaluated. Releases to air may constitute a worker health and safety concern and must be addressed as part of the alternatives assessment process. Other cross media impacts, including transfer of contaminants from soils to ground water, surface water, or air, should be assessed and addressed in the assessment of corrective actions. Guidance for addressing air and soil transport and contamination is provided in USEPA (1989b) and USEPA (1989c).

Analyses should be conducted on treatment options to determine whether or not they are protective of human health and the environment. Environmental monitoring of exposure routes (air and water) may necessitate health monitoring for personnel involved in treatment activities if unacceptable levels of exposure are possible. On a case-by-case basis, implementation plans may require both forms of monitoring.

The development and screening of individual corrective measures requires an understanding of the physio-chemical relationships and interferences between the constituents and the sequence of treatment measures that must be implemented. Proper sequencing of treatment methods to produce a feasible remedial program must be evaluated to avoid interference between the presence of some constituents and the effective removal of the targeted compound. In addition, screening and design parameters of potential treatment options should be evaluated in the early stages of conceptual development and planning to eliminate technically unsuitable treatment methods. In general, selection of an appropriate treatment method will require the experience of a qualified professional and will necessitate a literature review of the best available treatment technologies.

Numerous case studies and published papers from scientific and engineering technical journals exist on treatability of specific compounds and groups of related compounds. Development of new technologies and refinements of technologies have been rapid. A compendium of available literature that includes treatment technologies for organic and inorganic contaminants, technology selection, and other sources of information (e.g., literature search data bases pertinent to ground-water extraction, treatment, and responses) is included in *Practical Guide for Assessing and Remediating Contaminated Sites* (USEPA, 1989e).

The general approach to remediation typically includes active restoration, plume containment, and source control as discussed below. The selection of a particular approach or combination of approaches must be based on the corrective action objectives. These general approaches are outlined in Table 5-3. It should be emphasized that the objective of a treatment program should be to restore ground water to pre-existing conditions or to levels below applicable ground-water protection standards while simultaneously restricting further releases of contaminants to ground water. Once treatment objectives are met, the chance of further contamination should be mitigated to the extent practicable.

Active Restoration

Active restoration generally includes ground-water extraction, followed by onsite or offsite wastewater treatment. Offsite wastewater treatment may include sending the contaminated water to a local publicly owned treatment works (POTW) or to a facility designed to treat the contaminants of concern. Treated ground water may be re-injected, sent to a local POTW, or discharged to a local body of surface water, depending on local, State, and Federal requirements. Typical treatment practices that may be implemented include coagulation and precipitation of metals, chemical oxidation of a number of organic compounds, air stripping to remove volatile organic compounds, and biological degradation of other organics.

The rate of contaminant removal from ground water will depend on the rate of ground-water removal, the cation exchange capacity of the soil, and partition coefficients of the constituents sorbed to the soil (USEPA, 1988). As the concentration of contaminants in the ground water is reduced, the rate at which constituents become partitioned from the soil to the aqueous phase may also be reduced. The amount of flushing of the aquifer material required to remove the contaminants to an acceptable level will generally determine the time frame required for restoration. This time frame is site-specific and may last indefinitely.

In-situ methods may be appropriate for some sites, particularly where pump and treat technologies create serious adverse effects or where it may be financially prohibitive. In-situ methods may include biological restoration requiring pH control, addition of specific micro-organisms, and/or addition of nutrients and substrate to augment and encourage degradation by indigenous microbial populations. Bioremediation requires laboratory treatability studies and pilot field studies to determine the feasibility and the reliability of full-scale treatment. It must be demonstrated that the treatment techniques will not cause degradation of a target chemical to another compound that has unacceptable health risks and that is subject to further degradation. Alternative in-situ methods may also be designed to increase the effectiveness of desorption or removal of contaminants from the aquifer matrix. Such methodologies may include steam stripping, soil flushing, vapor extraction, thermal desorption, and solvent washing, and extraction for removal of strongly sorbed organic compounds. These methods also may be used in unsaturated zones where residual contaminants may be sorbed to the geologic matrix during periodic fluctuations of the water table. Details of in-situ methods may be found in several sources: USEPA (1988); USEPA (1985); and Eckenfelder (1989).

Plume Containment

The purpose of plume containment is to limit the spread of the contaminants. Methods to contain plume movement include passive hydraulic barriers, such as grout curtains and slurry walls, and active gradient control systems involving pumping wells and french drains. The types of aquifer characteristics that favor plume containment include:

- Water naturally unsuited for human consumption

- Contaminants present in low concentration with low mobility

- Low potential for exposure to contaminants and low risk associated with exposure

- Low transmissivity and low future user demand.

Often, it may be advantageous for the owner or operator to consider implementing ground-water controls to inhibit further contamination or the spread of contamination. If ground-water pumping is considered for capturing the leading edge of the contaminant plume, the contaminated water must be managed in conformance with all applicable Federal and State requirements. Under most conditions, it is necessary to consult with the regulatory agencies prior to initiating an interim remedial action.

Source Control

Source control measures should be evaluated to limit the migration of the plume. The regulation does not limit the definition of source control to exclude any specific type of remediation. Remedies must control the source to reduce or eliminate further releases by identifying and locating the cause of the release (e.g., torn geomembrane, excessive head due to blocked leachate collection system, leaking leachate collection well or pipe). Source control measures may include the following:

- Modifying the operational procedures (e.g., banning specific wastes or lowering the head over the leachate collection system through more frequent leachate removal)

- Undertaking more extensive and effective maintenance activities (e.g., excavate waste to repair a liner failure or a clogged leachate collection system)

- Preventing additional leachate generation that may reach a liner failure (e.g., using a portable or temporary rain shelter during operations or capping landfill areas that contribute to leachate migrating from identified failure areas).

In extreme cases, excavation of deposited wastes for treatment and/or offsite disposal may be considered.

Public Participation

The owner or operator is required to hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Notifications, such as contacting local public agencies, town governments, and State/Tribal governments, posting a notice in prominent local newspapers, and making radio announcements are effective. The public meeting should provide a detailed discussion of how the owner or operator has addressed the factors at §258.56(c)(1)-(4).

5.15 SELECTION OF REMEDY 40 CFR §258.57 (a)-(b)

5.15.1 Statement of Regulation

(a) Based on the results of the corrective measure assessment conducted under §258.56, the owner or operator must select a remedy that, at a minimum, meets the standards listed in paragraph (b) below. The owner or operator must notify the State Director, within 14 days of selecting a remedy, that a report describing the selected remedy has been placed in the operating record and how it meets the standards in paragraph (b) of this section.

(b) Remedies must:

(1) Be protective of human health and the environment;

(2) Attain the ground-water protection standard as specified pursuant to §§258.55(h) or (i);

(3) Control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of Appendix II constituents into the environment that may pose a threat to human health or the environment; and

(4) Comply with standards for management of wastes as specified in §258.58(d).

5.15.2 Applicability

These provisions apply to facilities that have been required to perform corrective measures. The selection of a remedy is closely related to the assessment process and cannot be accomplished unless a sufficiently thorough evaluation of alternatives has been completed. The process of documenting the rationale for selecting a remedy requires that a report be placed in the facility operating record that clearly defines the corrective action objectives and demonstrates why the selected remedy is anticipated to meet those objectives. The State Director must be notified within 14 days of the placement of the report in the operating records of the facility. The study must identify how the remedy will be protective of human health and the environment, attain the GWPS (either background, MCLs, or, in approved States, health-based standards, if applicable), attain source control objectives, and comply with waste management standards.

5.15.3 Technical Considerations

The final method selected for implementation must satisfy the criteria in §258.57(b)(1)-(4). The report documenting the capability of the selected method to meet these four criteria should include such information as:

- Theoretical calculations
- Comparison to existing studies and results of similar treatment case histories
- Bench-scale or pilot-scale treatability test results
- Waste management practices.

The demonstration presented in the report must document the alternative option selection process.

5.16 SELECTION OF REMEDY 40 CFR §258.57 (c)

5.16.1 Statement of Regulation

(c) In selecting a remedy that meets the standards of §258.57(b), the owner or operator shall consider the following evaluation factors:

(1) The long- and short-term effectiveness and protectiveness of the potential remedy(s), along with the degree of certainty that the remedy will prove successful based on consideration of the following:

(i) Magnitude of reduction of existing risks;

(ii) Magnitude of residual risks in terms of likelihood of further releases due to waste remaining following implementation of a remedy;

(iii) The type and degree of long-term management required, including monitoring, operation, and maintenance;

(iv) Short-term risks that might be posed to the community, workers, or the environment during implementation of such a remedy, including potential threats to human health and the environment associated with excavation, transportation, and redisposal or containment;

(v) Time until full protection is achieved;

(vi) Potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, redisposal, or containment;

(vii) Long-term reliability of the engineering and institutional controls; and

(viii) Potential need for replacement of the remedy.

(2) The effectiveness of the remedy in controlling the source to reduce further releases based on consideration of the following factors:

(i) The extent to which containment practices will reduce further releases;

(ii) The extent to which treatment technologies may be used.

(3) The ease or difficulty of implementing a potential remedy(s) based on consideration of the following types of factors:

(i) Degree of difficulty associated with constructing the technology;

(ii) Expected operational reliability of the technologies;

(iii) Need to coordinate with and obtain necessary approvals and permits from other agencies;

(iv) Availability of necessary equipment and specialists; and

(v) Available capacity and location of needed treatment, storage, and disposal services.

(4) Practicable capability of the owner or operator, including a consideration of the technical and economic capability.

(5) The degree to which community concerns are addressed by a potential remedy(s).

5.16.2 Applicability

These provisions apply to facilities that are selecting a remedy for corrective action. The rule presents the considerations and factors that the owner or operator must evaluate when selecting the appropriate corrective measure.

5.16.3 Technical Considerations

The owner or operator must consider specific topics to satisfy the performance criteria under selection of the final corrective measure. These topics must be addressed in the report documenting the selection of a particular corrective action. The general topic areas that must be considered include the following:

- The anticipated long- and short-term effectiveness of the corrective action
- The anticipated effectiveness of source reduction efforts
- The ease or difficulty of implementing the corrective measure
- The technical and economic practicable capability of the owner or operator
- The degree to which the selected remedy will address concerns raised by the community.

Effectiveness of Corrective Action

In selecting the remedial action, the anticipated long-term and short-term effectiveness should be evaluated. Long-term effectiveness focuses on the risks remaining after corrective measures have been taken. Short-term effectiveness addresses the risks during construction and implementation of the corrective measure. Review of case studies where similar technologies have been applied provide the best measures to judge technical uncertainty, especially when relatively new technologies are applied. The long-term, post-cleanup effectiveness may be judged on the ability of the proposed remedy to mitigate further releases of contaminants to the environment, as well as on the feasibility of the proposed remedy to meet or exceed the GWPSs. The owner or operator must make a reasonable effort to estimate and quantify risks, based on exposure pathways and estimates of exposure levels and durations. These estimates include risks for both ground-water and cross-media contamination.

The source control measures that will be implemented, including excavation, transportation, re-disposal, and containment, should be evaluated with respect to potential exposure and risk to human health and the environment. The source control measures should be viewed as an integral component of the overall corrective action. Health considerations must address monitoring risks to workers and the general public and provide contingency plans should an unanticipated exposure occur. Potential exposure should consider both long- and short-term cases before, during, and after implementation of corrective actions.

The time to complete the remedial activity must be estimated, because it will have direct financial impacts on the project management needs and financial capability of the owner or operator to meet the remedial objectives. The long-term costs of the remedial alternatives and the long-term financial condition of the owner or operator should be reviewed carefully. The implementation schedule should indicate quality control measures to assess the progress of the corrective measure.

The operational reliability of the corrective measures should be considered. In addition, the institutional controls and management practices developed to assess the reliability should be identified.

Effectiveness of Source Reduction

Source control measures identified in previous sections should be discussed in terms of their expected effectiveness. If source control consists of the removal and re-disposal of wastes, the residual materials, such as contaminated soils above the water table, should be quantified and their potential to cause further contamination evaluated. Engineering controls intended to upgrade or repair deficient conditions in landfill component systems, including cover systems, should be quantified in terms of anticipated effectiveness according to current and future conditions. This assessment may indicate to what extent it is technically and financially practicable to make use of existing technologies. The decision against using a certain technology may be based on health considerations and the potential for unacceptable exposure(s) to both workers and the public.

Implementation of Remedial Action

The ease of implementing the proposed remedial action will affect the schedule and startup success of the remedial action. The following key factors need to be assessed:

- The availability of technical expertise
- Construction of equipment or technology
- The ability to properly manage and dispose of wastes generated by treatment
- The likelihood of obtaining local permits and public support for the proposed project.

Technical considerations, including pH control, ground-water extraction feasibility, or the ability to inject nutrients, may need to be considered, depending on the proposed treatment method. Potential impacts, such as potential cross-media contamination, need to be reviewed as part of the overall feasibility of the project.

The schedule of remedial activities should identify the start and end points of the following periods:

- Permitting phase
- Construction and startup period, during which initial implementation success will be evaluated, including time to correct any unexpected problems
- Time when full-scale treatment will be initiated and duration of treatment period
- Implementation and completion of source control measures, including the timeframe for solving problems associated with interim management and disposal of waste materials or treatment residuals.

Items that require long lead times should be identified early in the process and those tasks should be initiated early to ensure that implementation occurs in the shortest practicable period.

Practical Capability

The owner or operator must be technically and financially capable of implementing the chosen remedial alternative and ensuring project completion, including provisions for future changes to the remedial plan after progress is reviewed. If either technical or financial capability is inadequate for a particular alternative, then other alternatives with similar levels of protectiveness should be considered for implementation.

Community Concerns

The public meetings held during assessment of alternative measures are intended to elicit public comment and response. The owner or operator must, by means of meeting minutes and a record of written comments, identify which public concerns have been expressed and addressed by corrective measure options. In reality, the final remedy selected and implemented will be one that the State regulatory agency, the public, and the owner or operator agree to.

5.17 SELECTION OF REMEDY 40 CFR §258.57 (d)

5.17.1 Statement of Regulation

(d) The owner or operator shall specify as part of the selected remedy a schedule(s) for initiating and completing remedial activities. Such a schedule must require the initiation of remedial activities within a reasonable period of time taking into consideration the factors set forth in paragraphs (d) (1-8). The owner or operator must consider the following factors in determining the schedule of remedial activities:

(1) Extent and nature of contamination;

(2) Practical capabilities of remedial technologies in achieving compliance with ground-water protection standards established under §§258.55(g) or (h) and other objectives of the remedy;

(3) Availability of treatment or disposal capacity for wastes managed during implementation of the remedy;

(4) Desirability of utilizing technologies that are not currently available, but which may offer significant advantages over already available technologies in terms of effectiveness, reliability, safety, or ability to achieve remedial objectives;

(5) Potential risks to human health and the environment from exposure to contamination prior to completion of the remedy;

(6) Resource value of the aquifer including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users;

(iii) Ground-water quantity and quality;

(iv) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituent;

(v) The hydrogeologic characteristic of the facility and surrounding land;

(vi) Ground-water removal and treatment costs; and

(vii) The cost and availability of alternative water supplies.

(7) Practicable capability of the owner or operator.

(8) Other relevant factors.

5.17.2 Applicability

The requirements of §258.57(d) apply to owners or operators of all new units, existing units, and laterally expanded units at all facilities required to implement corrective actions. The requirements must be complied with prior to implementing corrective measures. The owner or operator must specify the schedule for remedial activities based on the following considerations:

- The size and nature of the contaminated area at the time the corrective measure is to be implemented
- The practicable capabilities of the remedial technology selected
- Available treatment and disposal capacity
- Potential use of alternative innovative technologies not currently available
- Potential risks to human health and the environment existing prior to completion of the remedy
- Resource value of the aquifer
- The practicable capability of the owner/operator
- Other relevant factors.

5.17.3 Technical Considerations

The time schedule for implementing and completing the remedial activity is influenced by many factors that should be considered by the owner or operator. The most critical factor is the nature and extent of the contamination, which significantly affects the ultimate treatment rate. The size of the treatment facility and the ground-water extraction and injection rates must be balanced for system optimization, capital resources, and remedial timeframe objectives. The nature of the contamination will influence the degree to which the aquifer must be flushed to remove adsorbed species. These factors, which in part define the practicable capability of the alternative (treatment efficiency, treatment rate, and replenishment of contaminants by natural processes), should be considered when selecting the remedy.

In addition, the rate at which treatment may occur may be restricted by the availability or capacity to handle treatment residues and the normal flow of wastes during remediation. Alternative residue treatment or disposal capacity must be identified as part of the implementation plan schedule.

If contaminant migration is slow due to low transport properties of the aquifer, additional time may be available to evaluate the value of emerging and promising innovative technologies. The use of such technologies is not excluded as part of the requirement to implement a remedial action as soon as practicable. Delaying implementation to increase the availability of new technologies must be evaluated in terms of achievable cleanup levels, ultimate cost, additional environmental impact, and potential for increased risk to sensitive receptors. If a new technology clearly is superior to existing options in attaining remediation objectives, it may be appropriate to delay implementation. This may require that existing risks be controlled through interim measures.

In setting the implementation schedule, the owner or operator should assess the risk to human health and the environment within the timeframe of reaching treatment objectives. If the risk is unacceptable, considering health-based assessments of exposure paths and exposure limits, the implementation time schedule must be accelerated or the selected remedy altered to provide an acceptable risk level in a timely manner.

Establishment of the schedule also may include consideration of the resource value of the aquifer, as it pertains to current and future use, proximity to users, quality and quantity of ground water, agricultural value and uses (irrigation water source or impact on adjacent agricultural lands), and the availability of alternative supplies of water of similar quantity and quality. Based on these factors, a relative assessment of the aquifer's resource value to the local community can be established. Impacts to the resource and the degree of financial or health-related distress by users should be considered. The implementation timeframe should attempt to minimize the loss of value of the resource to users. The possibility that alternative water supplies will have to be developed as part of the remedial activities may need to be considered.

Because owners or operators may not be knowledgeable in remediation activities, reliance on the owner or operator to devise the schedule for remediation may be impracticable. In these instances, use of an outside firm to coordinate remediation scheduling may be necessary. Similarly, development of a schedule for which the owner or operator cannot finance, when other options exist that do allow for owner or operator financing, should be prevented.

5.18 SELECTION OF REMEDY 40 CFR §258.57 (e)-(f)

5.18.1 Statement of Regulation

(e) The Director of an approved State may determine that remediation of a release of an Appendix II constituent from a MSWLF unit is not necessary if the owner or operator demonstrates to the satisfaction of the Director of an approved State that:

(1) The ground water is additionally contaminated by substances that have originated from a source other than a MSWLF unit and those substances are present in concentrations such that cleanup of the release from the MSWLF unit would provide no significant reduction in risk to actual or potential receptors; or

(2) The constituent(s) is present in ground water that:

(i) Is not currently or reasonably expected to be a potential source of drinking water; and

(ii) Is not hydraulically connected with waters to which the hazardous constituents are migrating or are likely to migrate in a concentration(s) that would exceed the ground-water protection standards established under §258.55(h) or (i); or

(3) Remediation of the release(s) is technically impracticable; or

(4) Remediation results in unacceptable cross-media impacts.

(f) A determination by the Director of an approved State pursuant to paragraph (e) above shall not affect the authority of the State to require the owner or operator to undertake source control measures or other measures that may be necessary to eliminate or minimize further releases to the ground water, to prevent exposure to the ground water, or to remediate the ground water to concentrations that are technically practicable and significantly reduce threats to human health or the environment.

5.18.2 Applicability

The criteria under §258.57(e) and (f) apply in approved States only. Remediation of the release of an Appendix II constituent may not be necessary if 1) a source other than the MSWLF unit is partly responsible for the ground-water contamination, 2) the resource value of the aquifer is extremely limited, 3) remediation is not technically feasible, or 4) remediation will result in unacceptable cross-media impacts. The Director may determine that while total remediation is not required, source control measures or partial remediation of ground water to concentrations that are technically practicable and significantly reduce risks is required.

5.18.3 Technical Considerations

There are four situations where an approved State may not require cleanup of hazardous constituents released to ground water from a MSWLF unit. If sufficient evidence exists to document that the ground water is contaminated by a source other than the MSWLF unit, the Director of an approved State may grant a waiver from implementing some or all of the corrective measure requirements. The owner or operator must demonstrate that cleanup of a release from its MSWLF unit would provide no significant reduction in risk to receptors due to concentrations of constituents from the other source.

A waiver from corrective measures also may be granted if the contaminated ground water is not a current or reasonably expected potential future drinking water source, and it is unlikely that the hazardous constituents would migrate to waters causing an exceedance of GWPS. The owner or operator must demonstrate that the uppermost aquifer is not hydraulically connected with a lower aquifer. The owner or operator may seek an exemption if it can be demonstrated that attenuation, advection/dispersion or other natural processes can remove the threat to interconnected aquifers. The owner or operator may seek the latter exemption if the contaminated zone is not a drinking water resource.

The Director of an approved State may waive cleanup requirements if remediation is not technically feasible. In addition, the Director may wave requirements if remediation results in unacceptable cross-media impacts. A successful demonstration that remediation is not technically feasible must document specific facts that attribute to this demonstration. Technical impracticabilities may be related to the accessibility of the ground water to treatment, as well as the treatability of the ground water using practicable treatment technologies. If the owner or operator can demonstrate that unacceptable cross-media impacts are uncontrollable under a given remedial option (e.g., movement in response to ground-water pumping or release of volatile organics to the atmosphere) and that the no action option is a less risky alternative, then the Director of an approved State may determine that remediation is not necessary.

A waiver of remedial obligation does not necessarily release the owner or operator from the responsibility of conducting source control measures or minimal ground-water remediation. The State may require that source control be implemented to the maximum extent practicable to minimize future risk of releases of contaminants to ground water or that ground water be treated to the extent technically feasible.

5.19 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (a)

5.19.1 Statement of Regulation

(a) Based on the schedule established under §258.57(d) for initiation and completion of remedial activities the owner/operator must:

(1) Establish and implement a corrective action ground-water monitoring program that:

(i) At a minimum, meets the requirements of an assessment monitoring program under §258.55;

(ii) Indicates the effectiveness of the corrective action remedy; and

(iii) Demonstrates compliance with ground-water protection standard pursuant to paragraph (e) of this section.

(2) Implement the corrective action remedy selected under §258.57; and

(3) Take any interim measures necessary to ensure the protection of human health and the environment. Interim measures should, to the greatest extent practicable, be consistent with the objectives of and contribute to the performance of any remedy that may be required pursuant to §258.57. The following factors must be considered by an owner or operator in determining whether interim measures are necessary:

(i) Time required to develop and implement a final remedy;

(ii) Actual or potential exposure of nearby populations or environmental receptors to hazardous constituents;

(iii) Actual or potential contamination of drinking water supplies or sensitive ecosystems;

(iv) Further degradation of the ground water that may occur if remedial action is not initiated expeditiously;

(v) Weather conditions that may cause hazardous constituents to migrate or be released;

(vi) Risks of fire or explosion, or potential for exposure to hazardous constituents as a result of an accident or failure of a container or handling system; and

(vii) Other situations that may pose threats to human health and the environment.

5.19.2 Applicability

These provisions apply to facilities that are required to initiate and complete corrective actions.

The owner or operator is required to continue to implement its ground water assessment monitoring program to evaluate the effectiveness of remedial actions and to demonstrate that the remedial objectives have been attained at the completion of remedial activities.

Additionally, the owner or operator must take any interim actions to protect human health and the environment. The interim measures must serve to mitigate actual threats and prevent potential threats from being realized while a long-term comprehensive response is being developed.

5.19.3 Technical Considerations

Implementation of the corrective measures encompass all activities necessary to initiate and continue remediation. The owner or operator must continue assessment monitoring to anticipate whether interim measures are necessary, and to determine whether the corrective action is meeting stated objectives.

Monitoring Activities

During the implementation period, ground-water monitoring must be conducted to demonstrate the effectiveness of the corrective action remedy. If the remedial action is not effectively curtailing further ground water degradation or the spread of the contaminant plume, replacement of the system with an alternative measure may be warranted. The improvement rate of the condition of the aquifer must be monitored and compared to the cleanup objectives. It may be necessary to install additional monitoring wells to more clearly evaluate remediation progress. Also, if it becomes apparent that the GWPS will not be achievable technically, in a realistic time-frame, the performance objectives of the corrective measure must be reviewed and amended as necessary.

Interim Measures

If unacceptable potential risks to human health and the environment exist prior to or during implementation of the corrective action, the owner or operator is required to take interim measures to protect receptors. These interim measures are typically short-term solutions to address immediate concerns and do not necessarily address long-term remediation objectives. Interim measures may include activities such as control of ground-water migration through high-volume withdrawal of ground water or response to equipment failures that occur during remediation (e.g., leaking drums). If contamination migrates offsite, interim measures may include providing an alternative water supply for human, livestock, or irrigation needs. Interim measures also pertain to source control activities that may be implemented as part of the overall corrective action. This may include activities such as excavation of the source material or in-situ treatment of the contaminated source. Interim measures should be developed with consideration given to maintaining conformity with the objectives of the final corrective action.

5.20 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (b)-(d)

5.20.1 Statement of Regulation

(b) An owner or operator may determine, based on information developed after implementation of the remedy has begun or other information, that compliance with requirements of §258.57(b) are not being achieved through the remedy selected. In such cases, the owner or operator must implement other methods or techniques that could practicably achieve compliance with the requirements, unless the owner or operator makes the determination under §258.58(c).

(c) If the owner or operator determines that compliance with requirements under §258.57(b) cannot be practically achieved with any currently available methods, the owner or operator must:

(1) Obtain certification of a qualified ground-water specialist or approval by the Director of an approved State that compliance with requirements under §258.57(b) cannot be practically achieved with any currently available methods;

(2) Implement alternate measures to control exposure of humans or the environment to residual contamination, as necessary to protect human health and the environment; and

(3) Implement alternate measures for control of the sources of contamination, or for removal or decontamination of equipment, units, devices, or structures that are:

(i) Technically practicable; and

(ii) Consistent with the overall objective of the remedy.

(4) Notify the State Director within 14 days that a report justifying the alternative measures prior to implementing the alternative measures has been placed in the operating record.

(d) All solid wastes that are managed pursuant to a remedy required under §258.57, or an interim measure required under §258.58(a)(3), shall be managed in a manner:

(1) That is protective of human health and the environment; and

(2) That complies with applicable RCRA requirements.

5.20.2 Applicability

The requirements of the alternative measures are applicable when it becomes apparent that the remedy selected will not achieve the GWPSs or other significant objectives of the remedial program (e.g., protection of sensitive receptors). In determining that the selected corrective action approach will not achieve desired results, the owner or operator must implement alternate corrective measures to achieve the GWPSs. If it becomes evident that the cleanup goals are not technically obtainable by existing practicable technology, the owner or operator must implement actions to control exposure of humans or the environment from residual contamination and to control the sources of contamination. Prior to implementing alternative measures, the owner or operator must notify the Director of an approved State within 14 days that a report justifying the alternative measures has been placed in the operating record.

All wastes that are managed by the MSWLF unit during corrective action, including interim and alternative measures, must be managed according to applicable RCRA requirements in a manner that is protective of human health and the environment.

5.20.3 Technical Considerations

An owner or operator is required to continue the assessment monitoring program during the remedial action. Through monitoring, the short and long term success of the remedial action can be gauged against expected progress. During the remedial action, it may be necessary to install additional ground-water monitoring wells or pumping or injection wells to adjust to conditions that vary from initial assessments of the ground-water flow system. As remediation progresses and data are compiled, it may become evident that the remediation activities will not protect human health and the environment, meet GWPSs, control sources of contamination, or comply with waste management standards. The reasons for unsatisfactory results may include:

- Refractory compounds that are not amenable to removal or destruction (detoxification)
- The presence of compounds that interfere with treatment methods identified for target compounds
- Inappropriately applied technology
- Failure of source control measures to achieve desired results
- Failure of ground-water control systems to achieve adequate containment or removal of contaminated ground water
- Residual concentrations above GWPSs that cannot be effectively reduced further because treatment efficiencies are too low
- Transformation or degradation of target compounds to different forms that are not amenable to further treatment by present or alternative technologies.

The owner or operator should compare treatment assumptions with existing conditions to determine if assumptions adequately depict site conditions. If implementation occurred as designed, the owner or operator should attempt to modify or upgrade existing remedial technology to optimize performance and to improve treatment effectiveness. If the existing technology is found to be unable to meet remediation objectives, alternative approaches must be evaluated that could meet these objectives while the present remediation is continued. During this re-evaluation period, the owner or operator may suspend treatment only if continuation of remedial activities clearly increases the threat to human health and the environment.

5.21 IMPLEMENTATION OF THE CORRECTIVE ACTION PROGRAM 40 CFR §258.58 (e)-(g)

5.21.1 Statement of Regulation

(e) Remedies selected pursuant to §258.57 shall be considered complete when:

(1) The owner or operator complies with the ground-water protection standards established under §§258.55(h) or (i) at all points within the plume of contamination that lie beyond the ground-water monitoring well system established under §258.51(a).

(2) Compliance with the ground-water protection standards established under §§258.55(h) or (i) has been achieved by demonstrating that concentrations of Appendix II constituents have not exceeded the ground-water protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in §258.53(g) and (h). The Director of an approved State may specify an alternative length of time during which the owner or operator must demonstrate that concentrations of Appendix II constituents have not exceeded the ground-water protection standard(s) taking into consideration:

(i) Extent and concentration of the release(s);

(ii) Behavior characteristics of the hazardous constituents in the ground water;

(iii) Accuracy of monitoring or modeling techniques, including any seasonal, meteorological, or other environmental variabilities that may affect the accuracy; and

(iv) Characteristics of the ground water.

(3) All actions required to complete the remedy have been satisfied.

(f) Upon completion of the remedy, the owner or operator must notify the State Director within 14 days that a certification that the remedy has been completed in compliance with the requirements of §258.58(e) has been placed in the operating record. The certification must be signed by the owner or operator and by a qualified ground-water specialist or approved by the Director of an approved State.

(g) When, upon completion of the certification, the owner or operator determines that the corrective action remedy has been completed in accordance with the requirements under paragraph (e) of this section, the owner or operator shall be released from the requirements for financial assurance for corrective action under §258.73.

§258.59 [Reserved].

5.21.2 Applicability

These criteria apply to facilities conducting corrective action. Remedies are considered complete when, after 3 consecutive years of monitoring (or an alternative length of time as identified by the Director), the results show significant statistical evidence that

Appendix II constituent concentrations are below the GWPSs. Upon completion of all remedial actions, the owner or operator must certify to such, at which point the owner or operator is released from financial assurance requirements.

5.21.3 Technical Considerations

The regulatory period of compliance is 3 consecutive years at all points within the contaminant plume that lie beyond the ground-water monitoring system unless the Director of an approved State specifies an alternative length of time. Compliance is achieved when the concentrations of Appendix II constituents do not exceed the GWPSs for a predetermined length of time. Statistical procedures in §258.53 must be used to demonstrate compliance with the GWPSs.

The preferred statistical method for comparison is to construct a 99 percent confidence interval around the mean of the last 3 years of data and compare the upper limit of the confidence interval to the GWPS. An upper limit less than the GWPS is considered significant evidence that the standard is no longer being exceeded. The confidence interval must be based on the appropriate model describing the distribution of the data.

Upon completion of the remedy, including meeting the GWPS at all points within the contaminant plume, the owner or operator must notify the State Director within fourteen days that a certification that the remedy has been completed has been placed in the operating record. The certification must be signed by the owner or operator and a qualified ground-water scientist or approved by the Director of an approved State. Upon completion of the remedial action, in accordance with §258.58(e), the owner or operator is released from the financial assurance requirements pertaining to corrective actions.

The Director of an approved State may require an alternate time period (other than 3 years) to demonstrate compliance. In determining an alternate period the Director must consider the following:

- The extent and concentration of the release(s)
- The behavior characteristics (fate and transport) of the hazardous constituents in the ground water (e.g., mobility, persistence, toxicity, etc.)
- Accuracy of monitoring or modeling techniques, including any seasonal, meteorological or other environmental variabilities that may affect accuracy
- The characteristics of the ground water (e.g., flow rate, pH, etc.).

Consideration of these factors may result in an extension or shortening of the time required to show compliance with remediation objectives.

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